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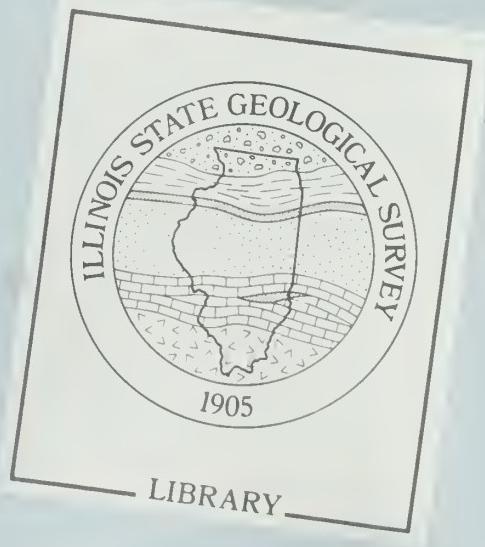
IL GEO SURVEY

Availability of Coal Resources in Illinois: Mt. Carmel Quadrangle, Southeastern Illinois

Russell J. Jacobson, Colin G. Treworgy,
Cheri Chenoweth, and Margaret H. Bargh

ILLINOIS MINERALS 114
1996

Department of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY



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Illinois State Geological Survey
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ABSTRACT

This report is one of a series that examines the availability of resources for mining in Illinois using current mining practices and technology. Interviews with mining experts from coal companies and state government indicated how environmental and regulatory restrictions, cultural features (towns, railroads), mining technology, and geologic conditions have affected the availability of coal in the Mt. Carmel Quadrangle. The Mt. Carmel Quadrangle, located in southeastern Illinois in the deepest part of the basin (region 4), contains many of the geologic and physiographic conditions common to the southern and southeastern part of the Illinois coal field.

Original and remaining resources for nine seams underlying the quadrangle total 1.1 billion tons, of which 415 million tons (38%) are estimated to be available for mining. Of the nearly 86 million tons of surface minable resources, 63% is estimated to be available, and 36% of the more than 1 billion tons of deep minable resources is estimated to be available. Technological factors, including seam thicknesses, roof conditions, stripping ratio, and size of mining block, account for 88% of the unavailable tonnage. Land use restrictions resulting from towns, railroads, cemeteries, and other cultural features account for the remaining 12%. Land use and technological factors probably restrict the mining of significant quantities of coal resources throughout the deepest part of the Illinois Basin.

INTRODUCTION

Accurate estimates of the amount of coal resources available for mining are needed for planning by mining companies, federal and state agencies, utilities, and other energy consumers and producers. Inventories of coal resources in Illinois provide relatively accurate estimates of the total amount of coal in the ground. Relatively little is known, however, regarding the percentage of the total coal resources that can actually be mined. Environmental and regulatory restrictions, the presence of towns and other cultural resources, current mining technology, geologic conditions, and other factors significantly reduce the amount of coal available for mining. This report is one of a series of reports in which the Illinois State Geological Survey (ISGS) examines the availability of coal resources for development.

The state was divided into seven regions to provide a framework for selecting quadrangles and extrapolating results to larger areas (fig. 1). The Mt. Carmel Quadrangle is located in eastern Wabash County along the Wabash River and the Illinois/Indiana state line. The area was selected as representative of many of the geologic and physiographic conditions in the deepest part of the Illinois Basin (region 4, fig. 1).

Mining experts from coal companies and state government were interviewed for information about how various factors might restrict the availability of the coal resources in the Mt. Carmel Quadrangle for mining. The information from these interviews was used to develop a set of criteria for defining available coal in the quadrangle. The location and quantity of available resources were delineated and tabulated using these criteria. Results from this and other quadrangle studies will be applied to each region and combined with coal-quality data to produce a statewide assessment of the availability and usability of coal resources. A complete description of the background and framework of these studies of coal availability is presented in the appendix.

Geologic and Physiographic Setting of Region 4

Region 4 (fig. 1) is located in southeastern Illinois. It is characterized by broad uplands covered with highly productive farmland and dissected by fairly narrow zones of gently rolling pasture and woodland that lie along streams and rivers.

Nearly 3% of the land in region 4 is covered by towns or other types of urban development. The remainder of the land is primarily used as farmland, pasture, water, forests, and wetlands. There are about 50 state parks and natural areas covering less than 1% of the land area of region 4. Many parts of this region have been extensively drilled for oil and gas, which may have some impact on coal mining.

Throughout region 4, the bedrock surface is concealed by a layer of glacial and alluvial deposits consisting of clay, silt, sand, and gravel. The bedrock surface is dissected by a well developed preglacial drainage system. The thicknesses of the glacial and alluvial deposits range from 50 to greater than 100 feet in the northern third of the region and from less than 50 to 200 feet in the remaining two-thirds. The

3 Region numbers

- Region boundaries
- Limit of Pennsylvanian
- - - County boundaries

- Proposed study areas
- This report
- Completed study area

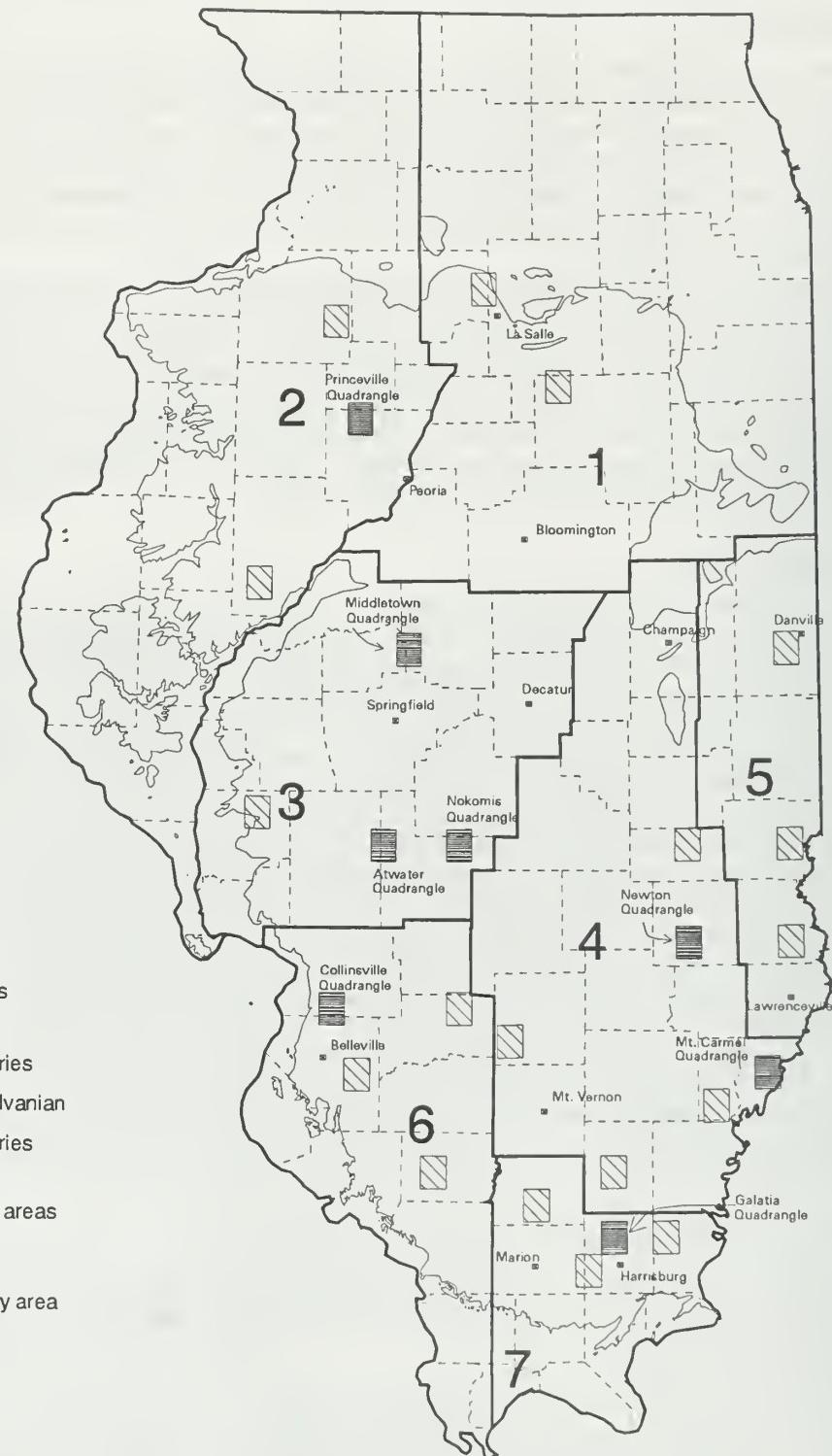


Figure 1 Coal resources regions and current quadrangles selected for coal availability evaluation.

thinner deposits (i.e., less than 50 feet) cover a preglacial upland surface, and the thicker deposits (greater than 200 feet) fill major bedrock valleys.

Region 4 encompasses the deep part of the Illinois Basin, an area known as the Fairfield Basin (fig. 2), and portions of the flanking shelves and uplifts. The Fairfield Basin and region 4 are bounded on the east by the La Salle Anticlinorium, which is a belt of sinuous branching monoclines with west-facing flanks. The upper limbs of these monoclines contain numerous elongate to circular, irregularly shaped anticlines and domes (Nelson 1991). On the west, the region is bordered by the Du Quoin Monocline and the associated Salem and Louden Anticlines, which separate the Fairfield Basin from the Western and Sparta Shelves of the Illinois Basin. Several other north-south anticlines, such as the Clay City Anticline, are found within the portion of the Fairfield Basin encompassed by region 4. Significant faults in the Wabash Valley Fault System, consisting of normal faults with displacements of up to nearly 500 feet, are found in the southeastern portion of region 4 (Nelson 1991).

Region 4 is underlain by several coal seams that range from several inches to more than 8 feet thick. Some of these coals (those in the McLeansboro Group of the upper Pennsylvanian) are shallow enough to be mined at the surface. However, these coals are typically thin and discontinuous throughout much of the region and thus do not constitute the bulk of the known coal resources in region 4. In this region, the major coal seams, found mostly in the Carbondale Formation (middle Pennsylvanian), lie at their maximum depths found in the Illinois Basin and are deep minable resources. Of particular interest are the Springfield and the Herrin Coals (informally called the No. 5 and No. 6 Coals, respectively) that contain the majority of the known resources in region 4 (figs. 3 and 4).

The Springfield Coal is well developed throughout most of the southern two-thirds of region 4 and is thickest adjacent to the Galatia Channel (fig. 3), an ancient drainage system that flowed through the area while the peat that formed the Springfield Coal was being deposited. The Springfield Coal has a low to medium sulfur content in large areas adjacent to this channel. The coal in region 4 lies at depths ranging from several hundred feet along the margins of the region to more than 1,200 feet in the east-central part of the region.

The Herrin Coal is also well developed in much of the southern two-thirds of region 4, except for a broad north-south zone bounded by the Clay City Anticline on the east and the Louden and Salem Anticlines on the west (see figs. 2 and 4). The Anvil Rock Channel, a channel that is much younger than the Herrin Coal and has removed the coal, passes through the northern quarter and southwestern corner of the region.

Deep minable resources of the Davis and Dekoven Coals are present in the southern part of region 4. To the north, these coals merge to form the Seelyville Coal, which also has significant deep minable resources in this region. Other coals, such as the Danville, Briar Hill, Houchin Creek, Survant, and Colchester, are also present in region 4, but they are typically too thin to be mined under current economic conditions.

Previous Investigations of Coal Resources in Region 4

Nance and Treworgy (1981) mapped coals that were potentially surface minable (at least 1.5 feet thick and less than 150 feet deep). They estimated 274 million tons of surface minable coal resources for region 4 in the final report of a 20-year series defining surface minable coal resources throughout the state.

At about the same time, availability of surface minable resources in region 4 was being evaluated in part by Treworgy et al. (1978), using additional restricting criteria. Their study demonstrated how factors such as stripping ratio, size and configuration of mining block, and certain categories of land use limit the availability of surface minable resources. In the 1978 study, approximately 189 million tons, or 68% of the figure estimated by Nance and Treworgy (1981), were found suitable for surface mining. Several important factors not considered in the 1978 study would further affect available resources. These factors, which were considered in the present study, include average stripping ratios of mine blocks; recovery of additional resources in minor seams as a byproduct of mining of thicker, underlying seams; and proximity of mine blocks to towns and important natural areas.

Treworgy and Bargh (1982) made the most recent evaluation of deep minable coal resources for the counties in region 4. In this study, the resources were examined in terms of their thickness, depth, proximity

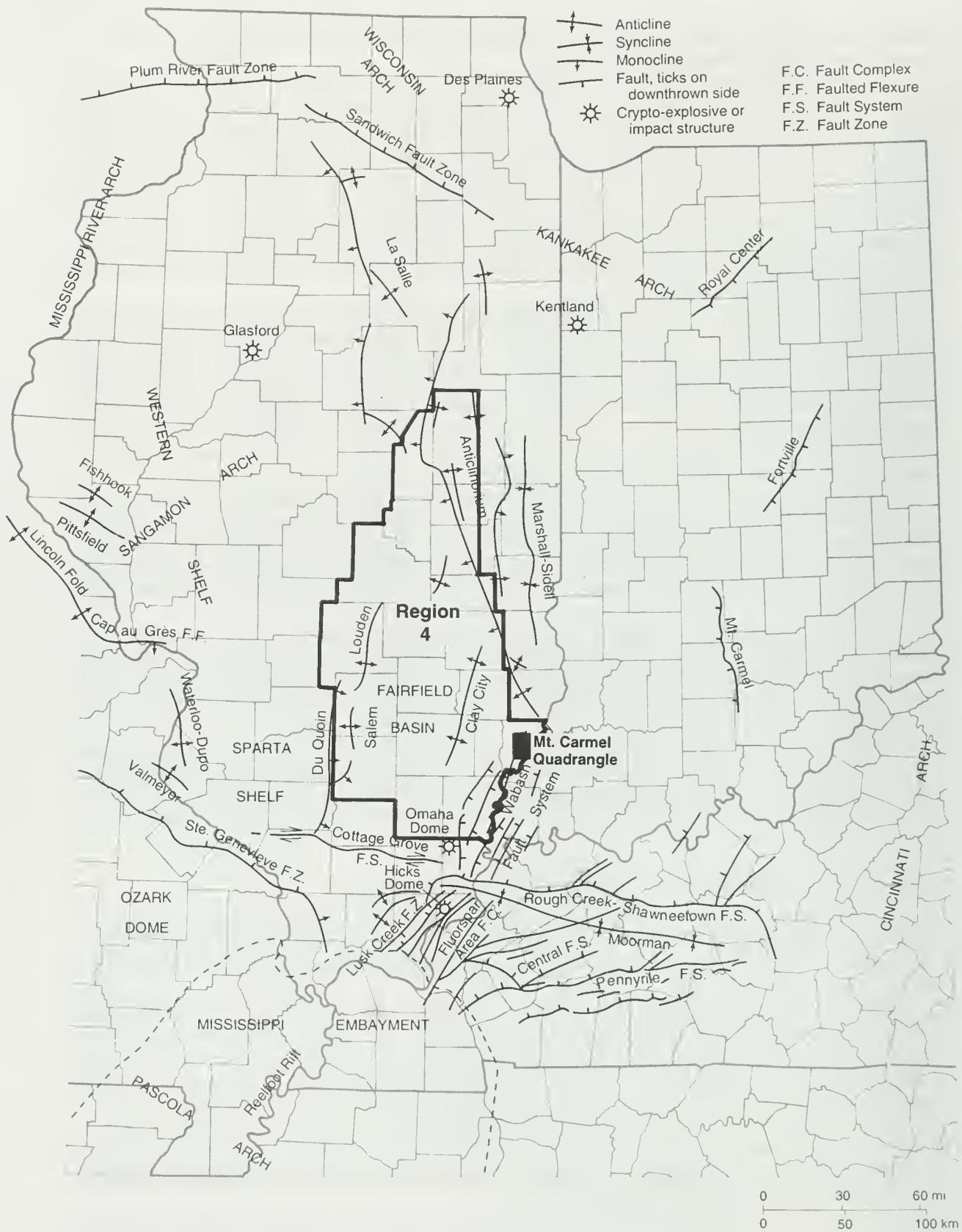


Figure 2 Major structural features of the Illinois Basin and vicinity (modified from Nelson 1991).

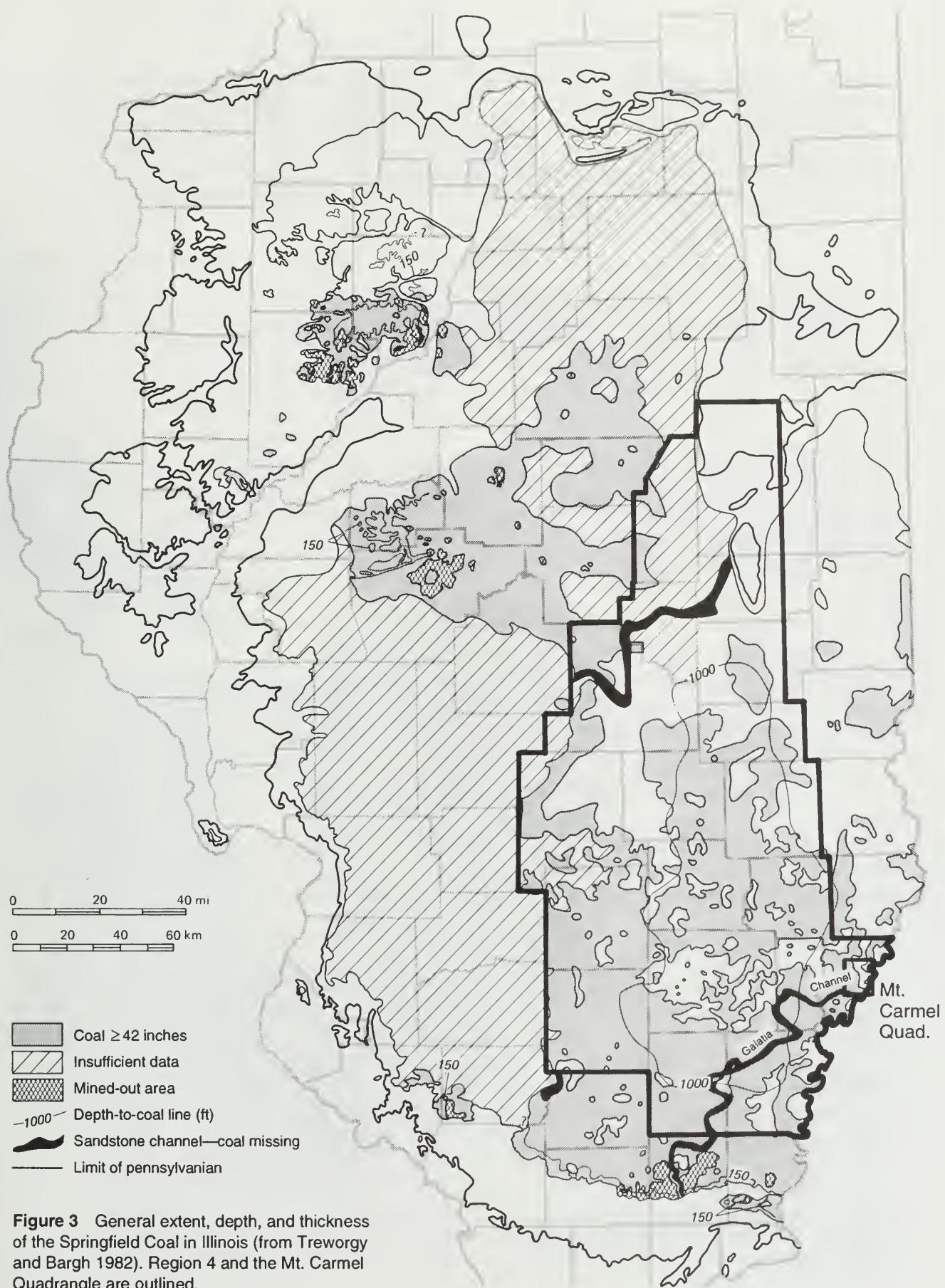


Figure 3 General extent, depth, and thickness of the Springfield Coal in Illinois (from Treworgy and Bargh 1982). Region 4 and the Mt. Carmel Quadrangle are outlined.

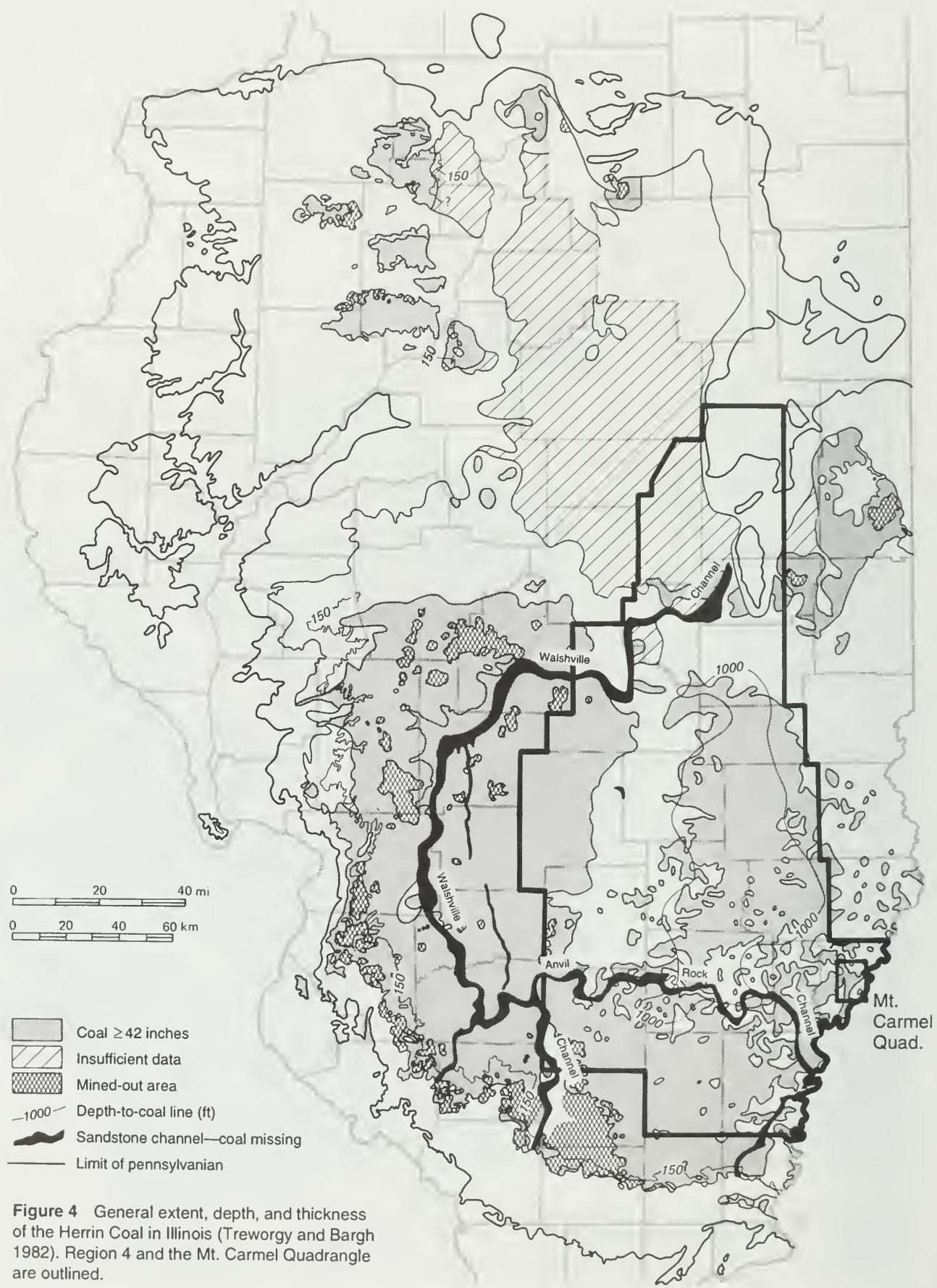


Figure 4 General extent, depth, and thickness of the Herrin Coal in Illinois (Treworgy and Bargh 1982). Region 4 and the Mt. Carmel Quadrangle are outlined.

to areas that were densely drilled for oil, and selected categories of land use (towns, interstate highways, public lands, and cemeteries). They estimated that region 4 contains a total of 68 billion tons of deep minable resources, of which 12% was ranked as having a high potential for development. Several other factors need to be evaluated, including thickness and composition of strata between seams, recovery of coal above or below previously mined areas, proximity to paleochannels and faulted areas, partings and clastic dikes in seams, roof and floor conditions, size and configuration of mining blocks, and thickness of bedrock overburden.

GEOLOGY OF THE MT. CARMEL QUADRANGLE

The subsurface geology of the Mt. Carmel Quadrangle was mapped using data from 948 boreholes in the study area and in the 4-mile zone surrounding it (fig. 5). The 4-mile buffer was used because the ISGS definition of inferred coal resources allows resources to be projected up to 4 miles from a datum point (Cady 1952). The top of bedrock was penetrated by 833 of these drill holes. The deepest of these wells were oil test holes that penetrated the entire succession of Pennsylvanian strata.

Glacial and Alluvial Deposits

Deposits of clay, silt, sand, and gravel cover the quadrangle. In more than three-quarters of the quadrangle, these deposits are less than 40 feet thick and overlie bedrock hills consisting of upper Pennsylvanian strata. These glacial and alluvial deposits of Quaternary age are thicker in bedrock valleys where they typically range from 40 to 80 feet and locally exceed 100 feet. This is particularly true in the valley of the Wabash River in the eastern part of the quadrangle where alluvial deposits more than 110 feet thick fill the preglacial bedrock valley of the Wabash River.

Bedrock Stratigraphy

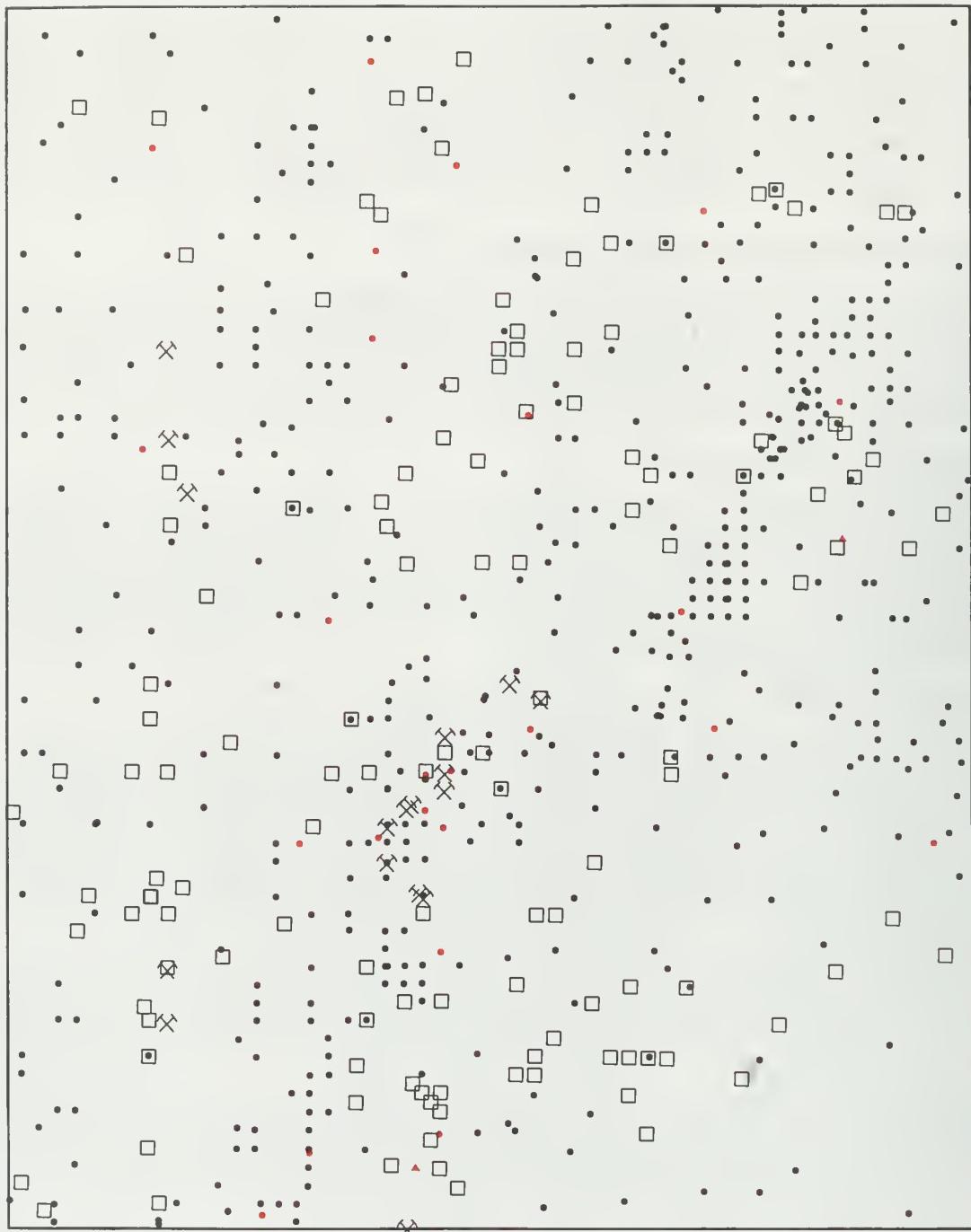
Coal-bearing Pennsylvanian bedrock strata that directly underlie the thin glacial deposits range from 1,500 to 1,800 feet thick. They consist primarily of shale, siltstone, sandstone, and coals. At least 12 coals were identified within the Mt. Carmel Quadrangle (fig. 6). Bedrock units, which dip to the west above the Flannigan Coal, have been eroded across most of the quadrangle; they are present as restricted outliers in the western part of the Mt. Carmel Quadrangle. Where present, these outliers only crop out locally at the surface where the glacial deposits are very thin. A brief description of the key units follows. A more detailed analysis of the stratigraphy of these units is presented in Nance and Treworgy (1981) and Willman et al. (1975).

Keensburg Coal The uppermost coal bed in the quadrangle is the Keensburg Coal, which is present in a small area in the west-central part of the quadrangle (fig. 7). It ranges from 1 to 4.5 feet thick and lies 25 to 75 feet below the surface along most of the subcrop (fig. 8). The coal is exposed at the surface in some places.

Friendsville Coal The Friendsville Coal is present only in the west half of the Mt. Carmel Quadrangle and has been eroded in two large bedrock valleys (fig. 9). The coal seam varies in thickness from less than 1 foot to more than 5.5 feet (fig. 9). It contains numerous shale and claystone partings; coal thickness alone ranges from less than 1 foot to slightly more than 4 feet. Generally, the Friendsville occurs at depths of from 25 to 125 feet (fig. 10); it crops out at the surface in some areas.

Witt Coal A thin coal that underlies the western three-quarters of the quadrangle, the Witt Coal lies roughly 75 to 100 feet below the Friendsville Coal. It is typically less than 1.5 feet thick, but it reaches 3.5 feet thick in several areas. The Witt lies at depths ranging from 25 feet along its subcrop in the east to more than 175 feet in the western part of the quadrangle.

Reel Limestone/Flannigan Coal The Reel Limestone and the underlying Flannigan Coal are widespread marker beds that occur approximately 35 feet beneath the Witt Coal. In the quadrangle, the Reel Limestone and Flannigan Coal lie roughly 85 to 100 feet above the Carthage Limestone and 100 to 150 feet below the Friendsville Coal. The Reel Limestone is typically 1 to 3 feet thick. The Flannigan Coal ranges from 0.5 to 1.5 feet thick. On the many resistivity logs used in this study, the two units are not distinguishable; they form a single resistivity peak. For an area just southwest of Mt. Carmel, Nance and



Data points

- coal test
- oil and gas test
- water well
- ✗ mine shaft
- ▲ outcrops



Figure 5 Datum points in the Mt. Carmel Quadrangle.

Treworgy (1981) reported that the Reel Limestone and about 1 foot of Flannigan Coal are exposed at low water level in the bed of the Wabash River (at Rochester, N½ NE, Sec. 14, T2S, R13W).

Mt. Carmel Sandstone The Mt. Carmel Sandstone is a well developed sandstone exposed in the bluff on the east bank of the Wabash River at Mt. Carmel (W½, Sec. 21, T1S, R12W). It varies from several feet to as much as 120 feet thick. Where the sandstone exceeds 80 feet in thickness, the top of the Mt. Carmel Sandstone is typically found about 10 feet below the Reel Limestone/Flannigan Coal. Elsewhere, as the sandstone thins, the interval increases from 10 to 60 feet.

Carthage Limestone The Carthage Limestone is one of the thicker limestones in the study area and varies in thickness from several feet to more than 10 feet. The Carthage Limestone, like the Macoupin and the West Franklin Limestones below, is a persistent marker bed across much of the Illinois Basin. It lies just below the Mt. Carmel Sandstone in the report area and is cut out in many places and replaced by the Mt. Carmel Sandstone (fig. 6).

Danville Coal The Danville Coal is widespread in the Illinois Basin. It varies from less than 1.5 feet to more than 4.5 feet thick in the quadrangle and lies approximately 175 to 200 feet below the West Franklin Limestone. Its depth ranges from 360 to 800 feet.

Herrin Coal The Herrin Coal constitutes the most abundant coal resource in Illinois. In the quadrangle, it lies 20 to 60 feet below the Danville Coal and varies from 2 feet to a little more than 5.5 feet thick (fig. 11).

Briar Hill Coal The Briar Hill Coal is a thin, but widespread coal seam that occurs roughly 40 to 70 feet below the Herrin Coal. The Briar Hill is typically thin, seldom reaching more than 2 feet thick; however, thicknesses of 3 to 4 feet are observed locally.

Springfield Coal The Springfield Coal is the second most abundant coal resource in Illinois; it is relatively thick and continuous over large areas of central and southeastern Illinois. The Springfield Coal is the most significant coal resource in the Mt. Carmel Quadrangle and is typically from 3.5 to more than 8 feet thick, except in a small area in the east half where it ranges from 2 to 3.5 feet thick (fig. 12). In the southwestern part of the quadrangle, a sandstone-filled paleochannel, known as the Galatia Channel, replaces the Springfield Coal (figs. 3, 6, 12). This channel formed contemporaneously with peat deposition, as demonstrated by the fact that the coal is (1) replaced within the channel and (2) commonly split by partings of shale and siltstone along the margins of this paleochannel. These partings formed when the paleoriver overflowed its banks during floods and dumped clay and silt in the peat swamp. The Springfield lies approximately from 75 to 100 feet below the Herrin Coal and 15 to 50 feet below the Briar Hill Coal. Throughout the quadrangle, the Springfield Coal ranges from slightly less than 500 to more than 900 feet deep (fig. 13).

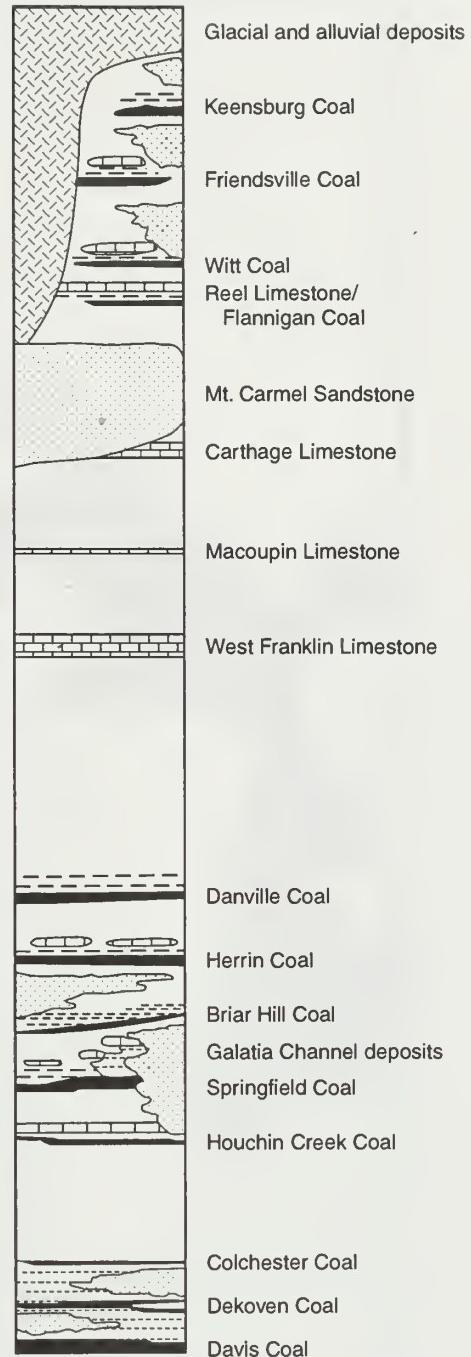
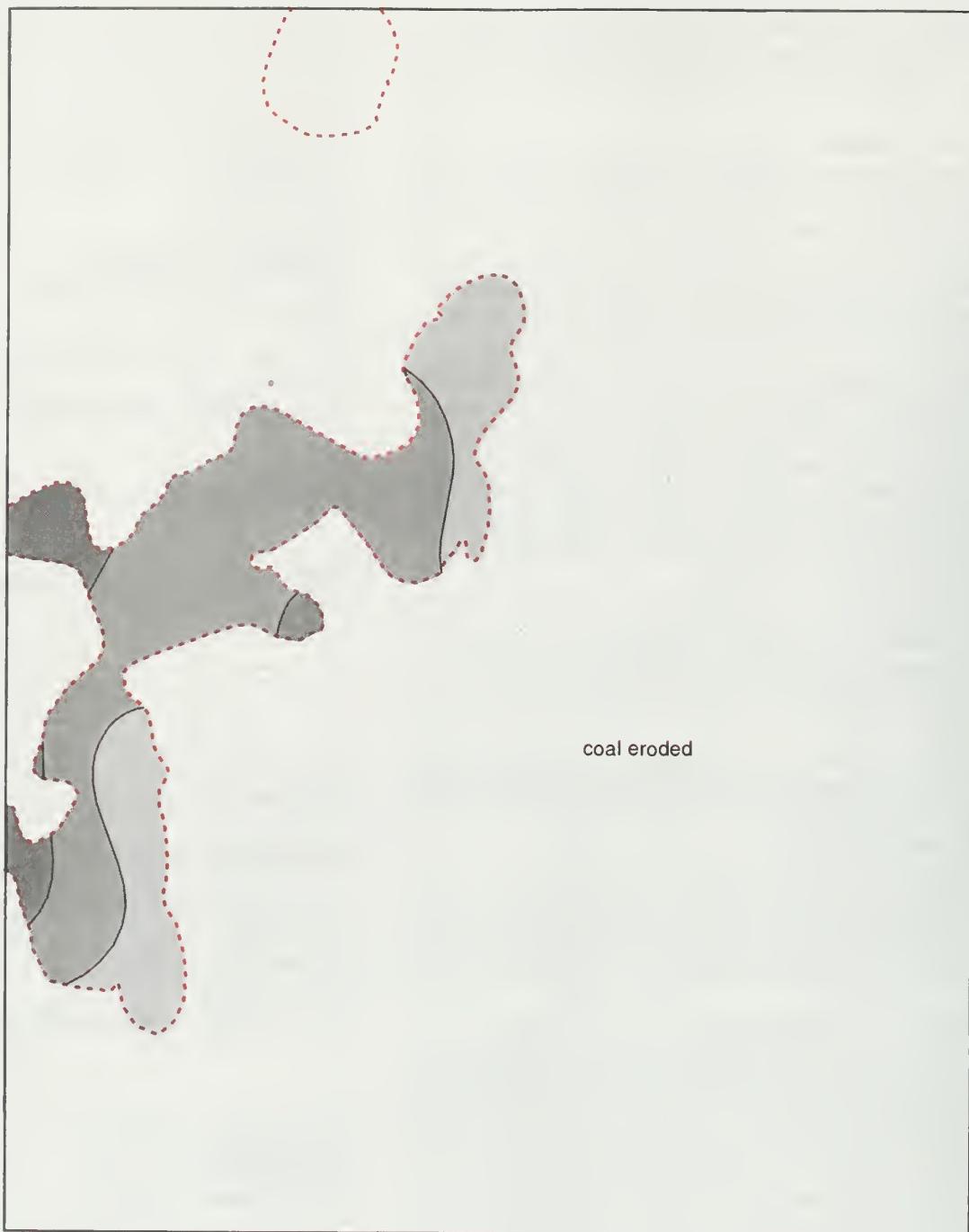


Figure 6 Selected stratigraphic units present in the Mt. Carmel Quadrangle.



Thickness of coal (feet)

white	<1.5
light gray	1.5–2.5
medium gray	2.5–3.5
dark gray	3.5–5.5

----- subcrop of Keensburg Coal



Figure 7 Thickness of the Keensburg Coal in the Mt. Carmel Quadrangle.



Thickness of overburden (feet)

[white box]	0-50
[grey box]	50-100

- - - subcrop of Keensburg Coal



0 1 mi

Figure 8 Depth of the Keensburg Coal in the Mt. Carmel Quadrangle.



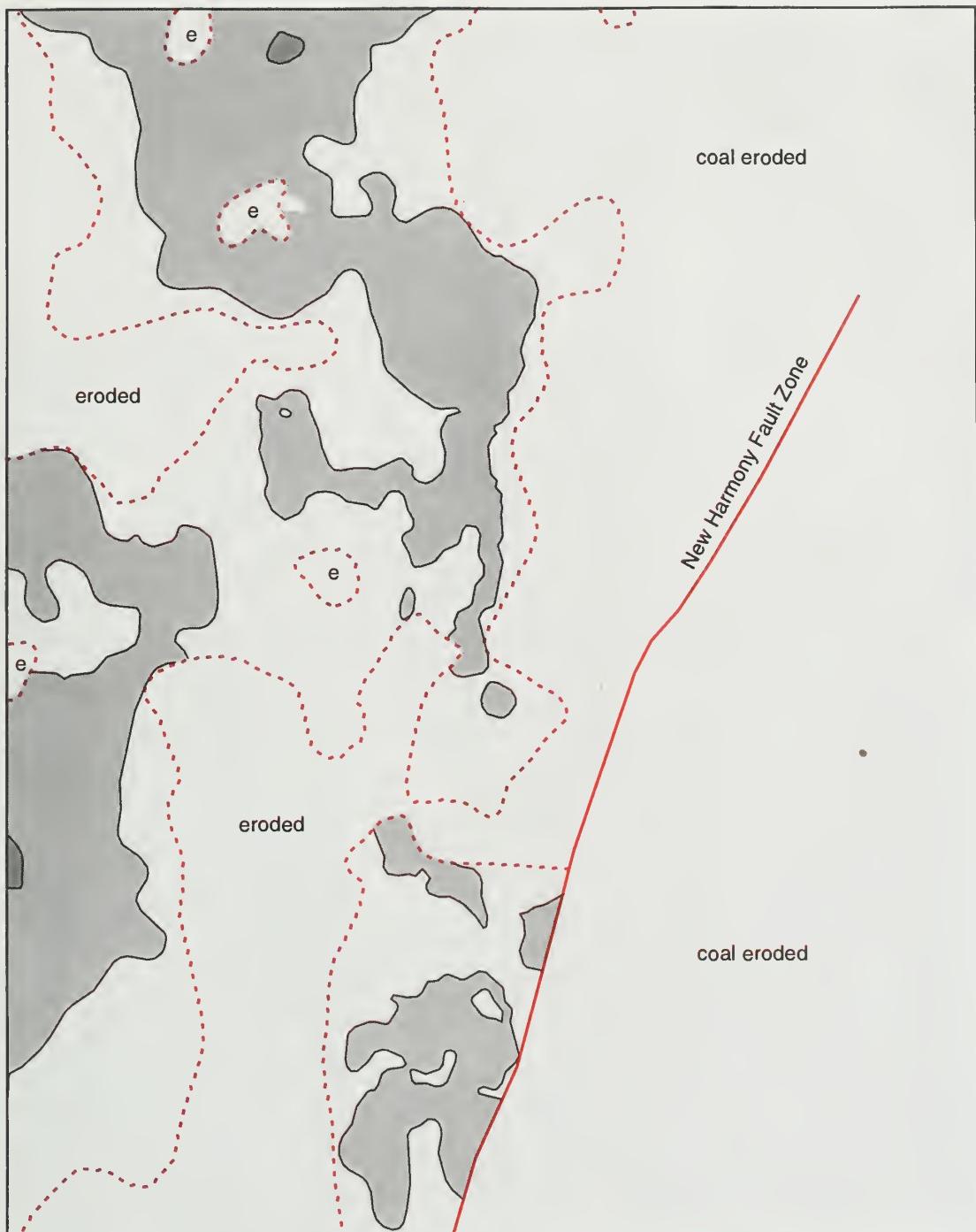
Thickness of coal (feet)

[White box]	<1.5
[Light gray box]	1.5–2.5
[Medium gray box]	2.5–3.5
[Dark gray box]	3.5–5.5
[Darkest gray box]	>5.5

----- subcrop of Friendsville Coal
 e coal eroded



Figure 9 Thickness of the Friendsville Coal in the Mt. Carmel Quadrangle.



Thickness of overburden (feet)

0–50
50–100
100–150

— subcrop of Friendsville Coal
e coal eroded



Figure 10 Depth of the Friendsville Coal in the Mt. Carmel Quadrangle.



Thickness of coal (feet)

Lightest Gray	<1.5
Medium-Light Gray	1.5–2.5
Medium Gray	2.5–3.5
Medium-Dark Gray	3.5–5.5
Darkest Gray	>5.5



Figure 11 Thickness of the Herrin Coal in the Mt. Carmel Quadrangle.



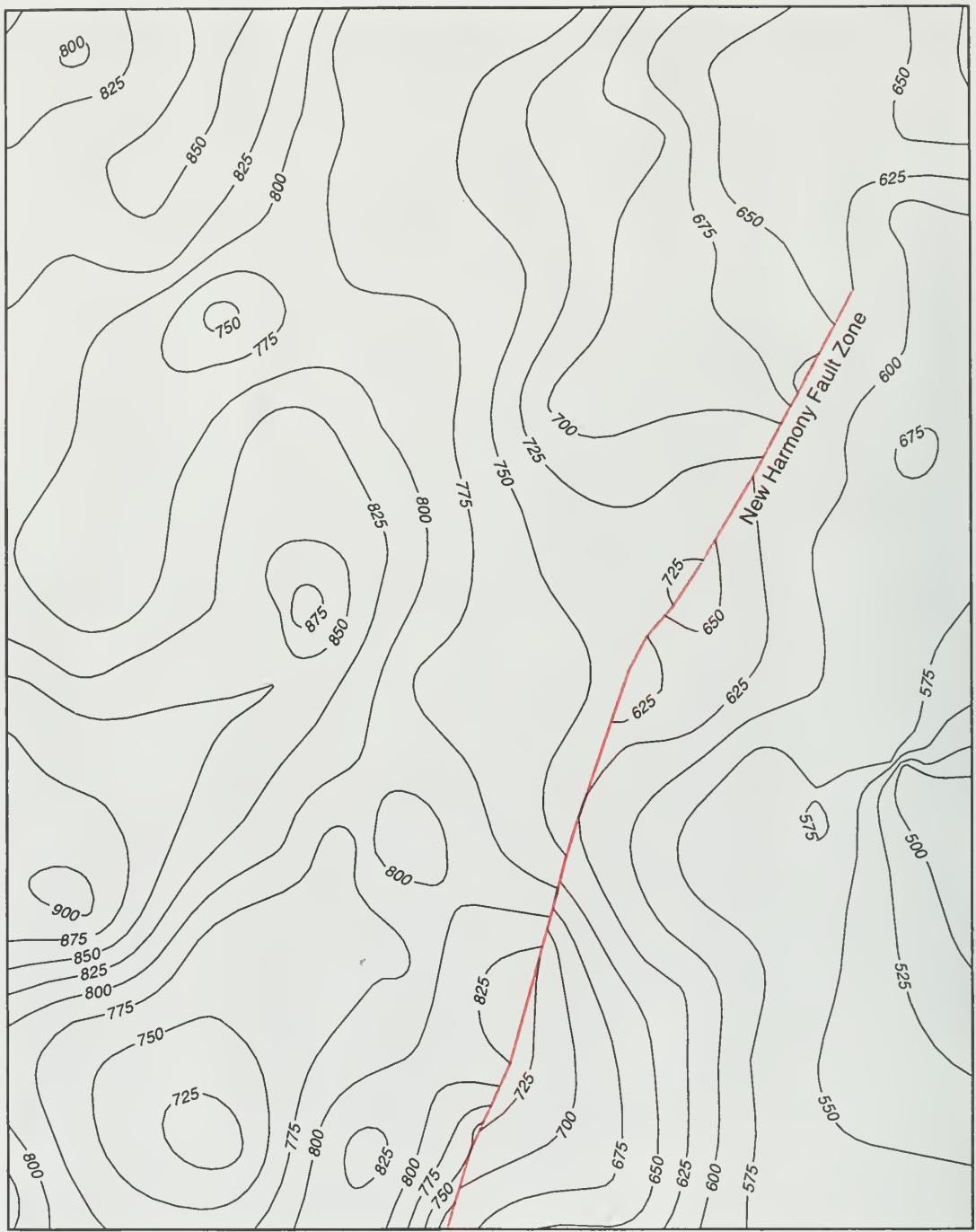
Thickness of coal (feet)

1.5–2.5
2.5–3.5
3.5–5.5
>5.5



0 1 mi

Figure 12 Thickness of the Springfield Coal in the Mt. Carmel Quadrangle.



-725- contour interval 25 feet



Figure 13 Depth of the Springfield Coal in the Mt. Carmel Quadrangle.

Houchin Creek Coal The Houchin Creek Coal is found roughly 50 to 120 feet below the Springfield Coal. The coal and its associated limestone and black shale roof are readily identifiable markers on most of the oil test wireline logs used in this report. The Houchin Creek Coal varies in thickness from less than 1 foot to slightly more than 3.5 feet. Most of the coal is thin, however, and ranges from less than 1 to 2.5 feet thick.

Survant Coal The Survant Coal occurs 80 to 140 feet below the Springfield Coal and 10 to 50 feet below the Houchin Creek Coal. The Survant is a somewhat discontinuous coal in most of the quadrangle. It is fairly thin, typically ranging from less than 1 to slightly more than 2 feet thick. Local thicknesses are estimated to be as much as 4 feet. This coal is not recognized in many of the logs and is inferred to be thin and discontinuous. Thus, no resources are estimated for the Survant Coal.

Colchester Coal The Colchester Coal is one of the most widespread coals in the Illinois Basin, but it is generally less than 1 foot thick in the study area. The coal and the directly overlying black shale (Mecca Quarry Shale) represent one of the most easily recognized stratigraphic marker beds on wireline logs. In this area, the Colchester lies 125 to 220 feet below the Springfield Coal.

Dekoven Coal The Dekoven Coal is thin and locally discontinuous. In the Mt. Carmel Quadrangle, it ranges from less than 1 to 2.5 feet thick; it reaches a little more than 3 feet thick in some areas. The Dekoven locally is split into two seams separated by as much as 10 feet of shale, siltstone, and sandstone. It lies 10 to 40 feet below the Colchester and 3 to 20 feet above the Davis Coal. Northeastward in the Illinois Basin, the Dekoven merges with the Davis to form the Seelyville Coal (Jacobson 1985).

Davis Coal The Davis Coal is fairly continuous in the Mt. Carmel Quadrangle. Along with the Springfield, Herrin, and Danville Coals, the Davis is identified as a significant deep minable coal resource in the quadrangle. Most of the coal is 3.5 to 5.5 feet thick, ranging from 0.5 to slightly more than 6 feet thick in a few areas (fig. 14). It lies 3 to 20 feet below the Dekoven Coal and 25 to 80 feet below the Colchester Coal.

Structure

The Mt. Carmel Quadrangle is located on the east flank of the Fairfield Basin. The bedrock strata dip generally west-southwestward into the Fairfield Basin at 50 to 125 feet per mile, averaging about 60 feet per mile (fig. 13). One exception to this general dip can be seen in the southwest quarter of the quadrangle (fig. 13), where the depth of the Springfield drops steeply for about 1 mile to the west of the fault and then rises about 100 feet in the next mile before resuming the plunge into the Fairfield Basin.

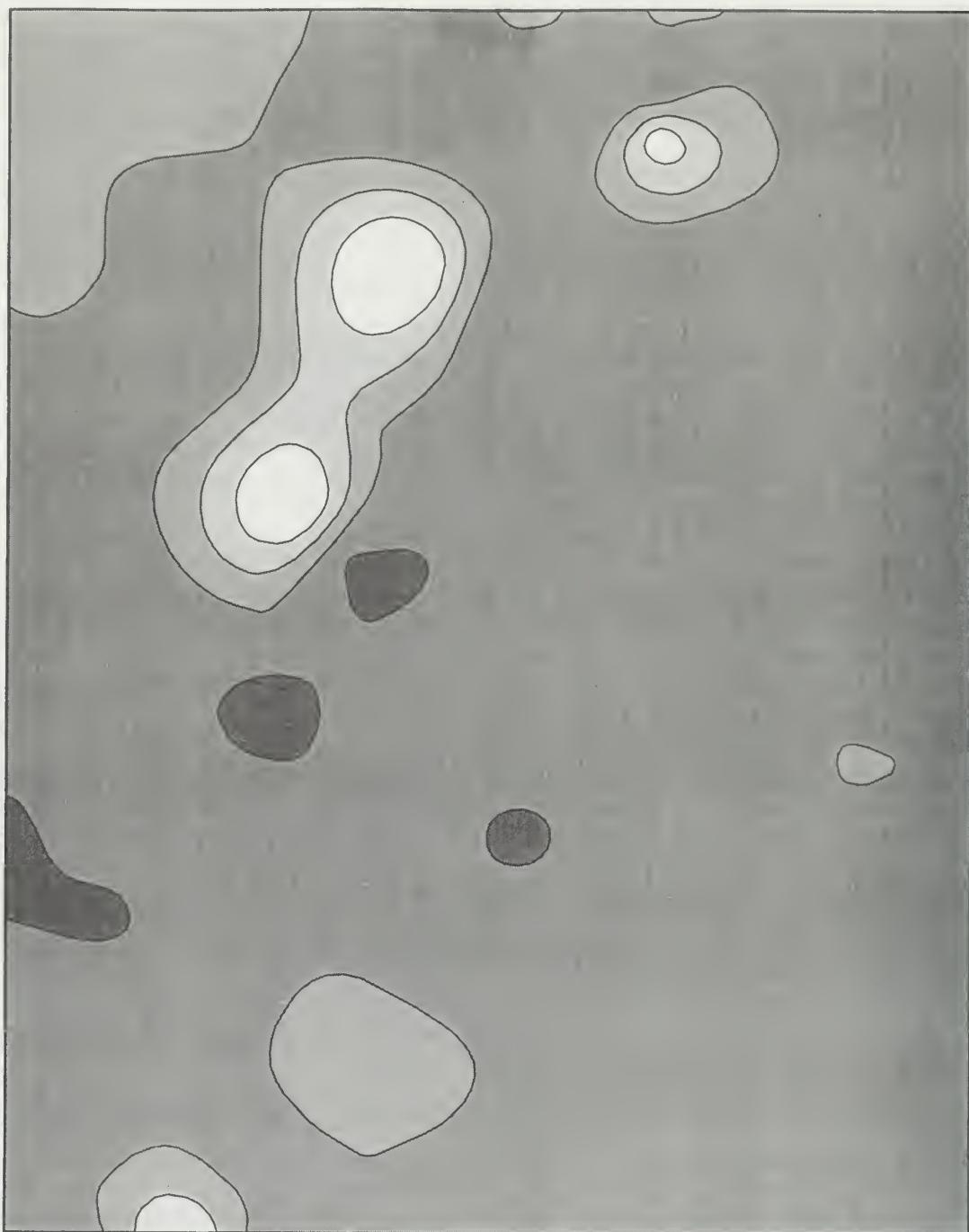
The Mt. Carmel Quadrangle is located at the north edge of the Wabash Valley Fault System. This fault system consists of a series of parallel, high-angle normal faults that form horsts and grabens (Bristol and Treworgy 1979). One of these normal faults (fig. 13), the New Harmony Fault Zone (Nelson 1995), traverses the quadrangle from its south-central part toward the northeast corner. The west side of the fault is downthrown with a maximum throw of about 300 feet (Bristol and Treworgy 1979) south of the study area. Throw on the New Harmony Fault in this quadrangle is roughly 50 to 150 feet (fig. 13).

LAND COVER AND OTHER FEATURES OF THE MT. CARMEL QUADRANGLE

The Mt. Carmel Quadrangle is largely a rural area (nearly 87%) used primarily for row crops and pasture. Approximately 4% of the area contains woodlands, consisting of oak, maple, and other hardwood trees. The town of Mt. Carmel is the county seat for Wabash County and has a population of more than 8,200 (fig. 15). Two other small towns, Friendsville and Patton, are located in the north-central and northeastern parts of the quadrangle, respectively. Collectively, these towns occupy about 8% of the quadrangle. Two railroad tracks owned by the Norfolk Southern Railroad radiate out of Mt. Carmel and cross the southern and eastern parts of the quadrangle.

The only major body of water is the Wabash River, which crosses the southeast and northeast edges of the quadrangle. The river channel of the Wabash occupies around 1% of the quadrangle and is about 1,000 feet wide. Its floodplain is as much as 2 miles wide in some areas.

The land surface of the quadrangle is covered by thin deposits of glacial or alluvial material, except in several deeper bedrock valleys. The topography consists of low hills with as much as 100 feet of relief, which largely reflects the character of the underlying Upper Pennsylvanian bedrock (sandstone and shale



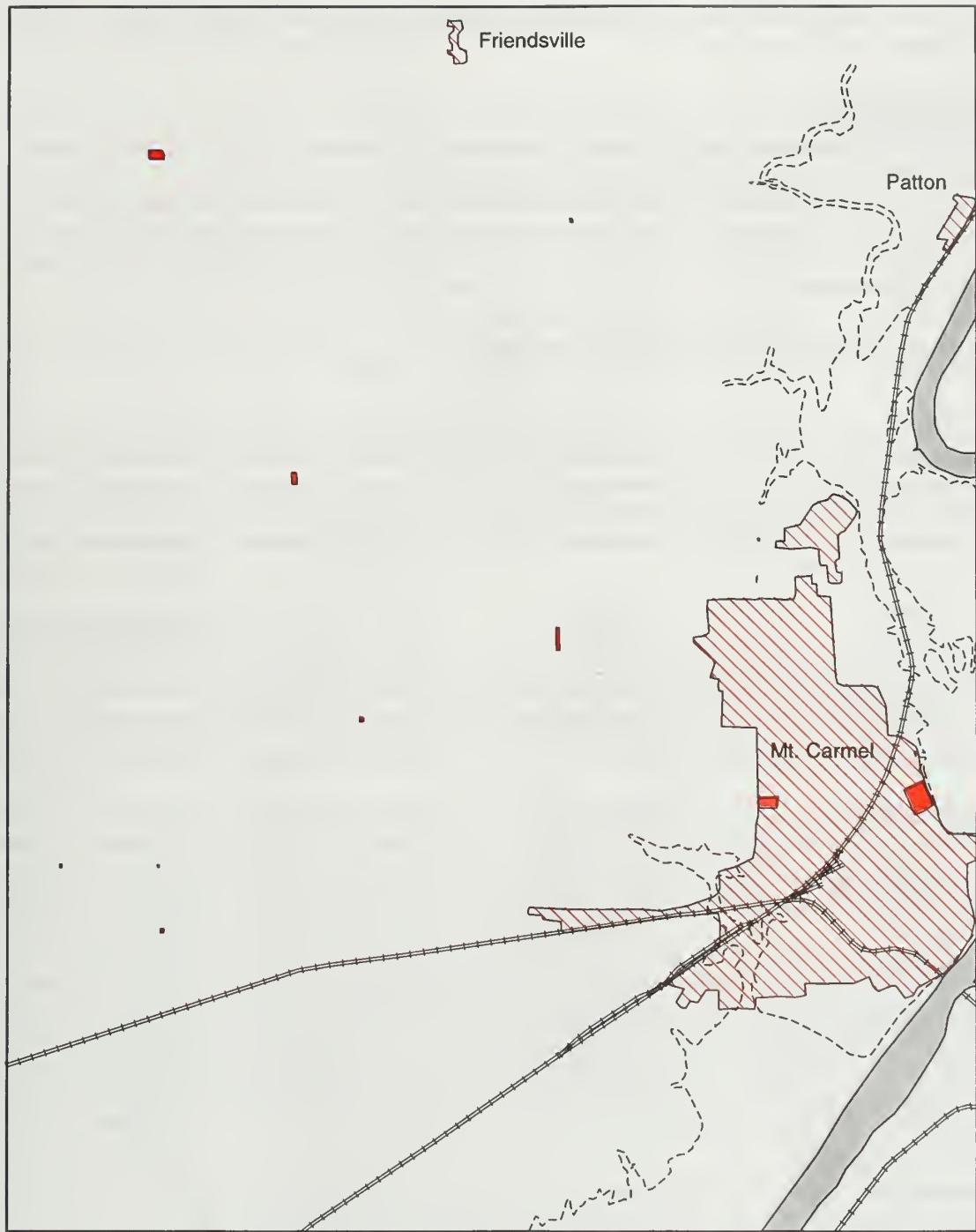
Thickness of coal (feet)

[Light Gray Box]	<1.5
[Medium-Light Gray Box]	1.5-2.5
[Medium Gray Box]	2.5-3.5
[Dark Gray Box]	3.5-5.5
[Darkest Gray Box]	>5.5



0 1 mi

Figure 14 Thickness of the Davis Coal in the Mt. Carmel Quadrangle.



Surface features

- [Shaded gray square] Wabash River
- [Red diagonal-hatched square] towns
- [Red square] cemeteries
- [Dashed line] railroads
- [Dashed line] limit of floodplain



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Figure 15 Surface features in the Mt. Carmel Quadrangle.

mostly). The drainage is well developed and dissects these hills extensively. Many of the exposures of bedrock can be found in ravines.

MINING HISTORY

About 15 small underground mines and one surface mine have operated in the Mt. Carmel Quadrangle. Although mining began in the 1860s, most mining took place during the period from the 1920s to early 1940s (table 1). All of these mines operated in the Friendsville Coal, which lies at relatively shallow depths in the west half of the quadrangle. Underground mining of the Friendsville occurred from several shafts as deep as 90 feet. The seam was reported to be 3.5 to 4 feet thick; the upper 1 to 1.5 feet of the seam had a canneloid appearance.

Table 1 Mines that operated in the Mt. Carmel Quadrangle.

Mine index	Company	Mine name	No.	Type	Years	Coal	Location
723	Lancaster C C	Lancaster	1	Shaft	1936–38	Friendsville	1S-13W-27
723	Maude Station Mine	Maude Station	1	Shaft	1938–39	Friendsville	1S-13W-27
723	Wilkerson,Ervin	Wilkerson		Shaft	1939–40	Friendsville	1S-13W-27
723	Anderson & Lindstrom C C	Anderson		Shaft	1940–41	Friendsville	1S-13W-27
723	Maude Station Mine		1	Shaft	1941–43	Friendsville	1S-13W-27
724	Thompson, C P	Thompson		Strip	1927–31	Friendsville	1S-13W-23
724	A & P C C	A & P		Strip	1931–36	Friendsville	1S-13W-23
725	Black Diamond C C	Black Diamond		Shaft	1924–27	Friendsville	1S-13W-23
725	Corden,Richard	Black Diamond		Shaft	1927–30	Friendsville	1S-13W-23
3894	Wirth, Chas	Wirth		Shaft	1923–36	Friendsville	1S-13W-23
3896	Briar Hill C C	Briar Hill	2	Shaft	1936–37	Friendsville	1S-13W-23
3896	Brown, W V	Seitz	2	Shaft	1937–38	Friendsville	1S-13W-23
3897	Old Maud Mine	Old Maud		Shaft	1927	Friendsville	1S-13W-27
4635	Bass, Ezra	Frye Mine		Shaft	?	Friendsville	1N-12W-19
4636	Grisby Mine	Grigsby		Shaft	?	Friendsville	1N-12W-31
4642	Roderick (before 1927)	Roderick	1	Shaft	1927–	Friendsville	1S-13W-3
4643	Roderick	Roderick	2	Shaft	1921–23	Friendsville	1S-13W-3
4644	Beck (about 1910)	Beck		Shaft	1910–10	Friendsville	1S-13W-10
4645	Bob Chapman Mine (about 1865)	Chapman		Shaft	1865–	?	1S-13W-13
4646	Simonds Mine (about 1870)	Simonds		Shaft	1870–70	?	1S-13W-13
4647	?	?		Shaft	?	?	1S-13W-22
4648	Wabash C C (2 mines)	Wallace		Shaft	?	Friendsville	1S-13W-23

FACTORS AFFECTING THE AVAILABILITY OF COAL IN THE MT. CARMEL QUADRANGLE

The availability of coal for future mining in the Mt. Carmel Quadrangle is limited by several factors. These were identified through interviews with mining engineers and geologists from four coal companies that have mines in geologic and physiographic settings similar to those found in the quadrangle. Staff members of the Illinois Department of Mines and Minerals (IDMM), the state agency responsible for permitting and inspecting mines, were also interviewed. Although this sampling of experts probably does not represent the views of all mining companies, it provides a reasonable basis for estimating the available coal resources in the Mt. Carmel Quadrangle.

Availability of coal must be evaluated with respect to the mining method that will most likely be used to recover the coal. In Illinois, coal is mined by both surface and underground methods. The equipment and procedures used in each method change in response to economic conditions, new technologies, and legal restrictions. This evaluation of coal availability is based on current mining practices of companies active in Illinois.

In a few cases, the values of factors that limit the availability of coal for mining are specified by law (e.g., the width of unmined coal to be left between underground mines). In most cases, however, the limits are based on a general consensus of mining experts (e.g., minimum coal thickness, maximum coal depth, minimum bedrock cover, and minimum size of mining block). The experts generally agreed on most criteria for defining available coal. Where they differed, the range of values has been given and the rationale described.

Surface Minable Coal

The criteria used to define coal available for surface mining in the Mt. Carmel Quadrangle (table 2) are, for the most part, identical to those used in the study of available coal in the Galatia Quadrangle (fig. 1) to the south (Treworgy et al. 1995). The following discussion is from the Galatia Quadrangle report and has been modified, where necessary, to describe the application of the criteria to coal resources in the Mt. Carmel Quadrangle.

Thickness of coal The use of large excavating equipment for removal of overburden and loading of coal results in the unavoidable loss of several inches of coal from the top and bottom of the seam. Additional coal is lost in transporting and washing the coal. These losses are higher as a percentage of the original coal in-place when the seam is thin. Seams less than a certain minimum thickness are impractical to mine because too much of the seam is lost when mining.

The U.S. Geological Survey (USGS) generally considers 14 inches to be the minimum seam thickness for surface minable coal but acknowledges that this minimum may vary from one region to another (Wood et al. 1983). The ISGS has traditionally used 18 inches as the minimum thickness for defining surface minable coal resources in Illinois (Smith 1957). The mining companies interviewed agreed that 18 inches is a reasonable minimum thickness for the main seam in a mining operation in this region. However, other coals present in the overburden will be recovered if they are at least 12 inches thick. In this area, for example, surface mines in the Friendsville Coal could mine the overlying Keensburg Coal as well, if it were at least 12 inches thick.

Thickness of overburden Most surface mines in Illinois use large draglines, shovels, or wheel excavators to remove overburden from the coal. Small draglines or a combination of small shovels and trucks are used in some mines. According to the engineers interviewed, these methods currently have an effective limit of 150 to 175 feet of overburden. Although small areas of thicker overburden (e.g., as a small ridge dividing a property) can be surface mined, underground mining methods are more economical for recovering large contiguous blocks of coal at depths greater than 175 feet.

Stripping ratio The stripping ratio is the number of cubic yards of overburden that must be removed to recover 1 ton of coal. Whereas the minimum thickness of coal and maximum thickness of overburden that can be mined are values controlled in part by technical factors such as mining equipment, the maximum stripping ratio is strictly an economic limit. Coals with high stripping ratios may be more economical to

mine by underground methods or remain unmined until the market price for coal rises relative to production costs.

Under present economic conditions, the maximum stripping ratio for a deposit is about 25 to 1, and the maximum average stripping ratio for a deposit must be less than 20 to 1. If two or more coals are present within the maximum overburden limit of 175 feet, their combined thickness may be used to calculate the stripping ratio.

Block size and configuration Opening a surface mine of any size entails certain fixed costs for exploration, land acquisition, mine planning, permitting, and construction of offices, facilities for equipment maintenance, coal cleaning, storage, and transportation. If a mine is to be profitable, the block of coal to be mined must contain more than enough tonnage to recover these fixed costs. A mining block for a surface mine does not have to be a contiguous deposit of coal; it may consist of two or more smaller blocks relatively close to each other and not separated by barriers (e.g., a river) that impede the movement of equipment. Blocks must also have a geometric configuration suitable for the anticipated mining methods. For example, a long, narrow deposit having a deeply buried subcrop is not suitable for area mining or small truck and shovel operations. Our interviews indicate that a mine block of 11 million tons of coal in-place (i.e., about 10 million tons recoverable) would be needed to develop a mine in the Mt. Carmel Quadrangle.

In some areas of the Illinois Basin, mines have been developed with only several hundred thousand tons of reserves. However, these are generally shallow deposits that can be mined with conventional earth-moving equipment, such as is used by construction companies. Also, these small coal deposits commonly have special quality characteristics (e.g., low sulfur and/or high Btu content) that allow them to be readily sold on the spot market. The coals in the Mt. Carmel Quadrangle that have limited availability due to block size (the Witt and Friendsville) are not attractive for small operations. The average overburden thickness is high, initial box cuts would have to be quite deep and, in the case of the Friendsville Coal, the seam has several rock partings, which would require the use of preparation facilities to produce a marketable coal.

Restricted mining in faulted areas The experts we interviewed told us that surface mining near faulted areas in the Mt. Carmel Quadrangle was not considered a major problem that would lead to a reduction of resources. However, through discussions with staff at Amex Coal Company, which is mining underground along the New Harmony Fault Zone just to the south of the quadrangle, we learned of some potential minor problems that may reduce coal availability in the western downthrown block. A substantial dip was locally present in the coal due to reverse drag, making it difficult to recover the coal in a narrow strip adjacent to the fault zone (Koehl and Meier 1983). This may also cause problems for surface mining as the coal dips down into the fault zone. Therefore, we calculated the resources that would be excluded by a 200-foot buffer along the New Harmony Fault Zone. Only about 46,000 tons of available surface minable coal (or 0.09% of the total) would be excluded in our final tabulations, we thus followed the practice of the companies interviewed and did not exclude any available resources because of faulting.

Land use restrictions State laws do not specifically prohibit surface mining of any area. However, rules governing the mining of certain features have the effect of prohibiting or severely restricting the mining of these areas. Cemeteries cannot be mined, for example, unless all surviving family members give permission to move the graves of their ancestors. Finding and notifying such family members is usually so time consuming and expensive that most cemeteries are not mined. In the Mt. Carmel Quadrangle, a buffer of about 200 feet would likely be left between surface mines and cemeteries.

Mining through towns or other large developed areas is also impractical because the cost of purchasing the surface property is likely to exceed the value of the coal. Although laws do not prohibit mining up to the edge of a town, companies are required to control dust levels and vibrations from blasting. These restrictions make it difficult to mine near towns. The distance that mining must be kept from populated areas is highly subjective and, to an extent, dependent on the general acceptance of surface mining in the area. The experts interviewed thought that surface mining could be conducted within 1,000 feet of developed areas in this quadrangle.

Surface mining through roads, railroads, pipelines, or transmission lines requires permission from the owners or governing authorities. Generally, it is less expensive to avoid all but minor roads and pipelines.

In the Mt. Carmel Quadrangle, a buffer of about 200 feet would likely be left between surface mines and major roads, railroads, pipelines, and transmission lines.

For engineering, environmental, and safety reasons, companies generally leave a buffer of unmined coal (usually 200 feet wide) around underground mine workings. In some cases, however, mining through a small abandoned underground mine may be necessary to access adjacent areas of unmined coal. The small mines in the Friendsville Coal (the only mines in the Mt. Carmel Quadrangle) are probably not of much consequence for surface mining and were not considered as restrictions in our evaluations.

Environmentally sensitive areas, such as floodplains, are potential restrictions to surface mining. In the case of the Mt. Carmel Quadrangle, this was not a consideration because none of the surface minable resources lie in the floodplain of the Wabash River.

Deep Minable Coal

Where thickness of overburden or the stripping ratio is too great for surface mining, coal must be mined by underground methods. There is no definite boundary between the areas requiring surface mining and underground mining. Rather, there is generally a zone where either method is technically feasible. The criteria used to identify coal available for underground mining in the Mt. Carmel Quadrangle (table 2) are

Table 2 Criteria used to define available coal in the Mt. Carmel Quadrangle.

Surface mining

Minimum seam thickness

- Main seam: 18 inches
- Overlying seams: 12 inches

Maximum depth

- 175 feet

Maximum stripping ratio

- 25:1

Maximum average stripping ratio

- 20:1

Minimum block size

- 11 million tons in-place (assumes existing preparation plants will be used)
- Restricted mining in some faulted areas

Land use restrictions

- 200 feet around mines, cemeteries, and railroads
- 1,000 feet around towns
- No buffer around oil wells

Underground mining

Minimum seam thickness

- 4 feet

Maximum in-seam parting

- 1 foot

No maximum depth

Minimum block size

- 80 million tons (in-place)

Poor mining conditions exclude Springfield Coal within 0.5 miles of Galatia Channel

Restricted mining in some faulted areas

Land use restrictions

- 200 feet around towns, cemeteries, and railroads
- No buffer around oil wells

similar to those used for the evaluation of the Galatia Quadrangle (Treworgy et al. 1995) and much of the following discussion has been taken from that report and adapted to the Mt. Carmel Quadrangle.

Thickness of coal The thickness of the seam controls the amount of coal that can be produced per acre and the ease of moving miners and machinery within the mine. Thin seams are more costly to mine because of the amount of roof control and longer haulage required per ton mined. Also, miners work more efficiently when they can move freely and the working face is fully visible. Equipment used for underground mining is selected for optimal performance within a limited range of seam thickness. If thicker coal is encountered in mining, a portion of the seam may be beyond the cutting height of the equipment and left unmined (generally as top coal). A more serious problem is coal thinner than the equipment design. This will require that roof or floor rock be mined along with the coal, a situation that slows mining operations as well as increases equipment wear and coal cleaning costs.

As noted earlier, the USGS considers all coals 14 inches or greater in thickness to be resources (Wood et al. 1983). The ISGS has traditionally used 28 inches as the minimum seam thickness for deep minable resources (Cady 1952). These thicknesses are far less than the minimum thickness currently considered minable in Illinois. The average thickness of coal mined in the state is about 6 feet. According to the experts interviewed, mining coal less than 4 feet thick is prohibitively expensive, although short spans of thinner coal and even rock may be mined to gain access to thicker coal. For example, other factors being equal, the cost of production from a 3-foot seam would be on the order of twice that of a 6-foot seam. Although there are examples of thin coals being mined in other parts of the country, these are due to special local conditions that either increase the value of the coal (e.g., a metallurgical grade coal) or reduce the cost of developing a mine (e.g., a seam outcropping along the side of a mountain eliminates the cost of a shaft and reduces exploration costs).

In-seam parting Deposition of the peat along the Galatia Channel was apparently interrupted periodically by water and sediment flowing out of the main channel. Partings in the coal and areas of thin or missing coal (due to erosion or lack of deposition) are commonly encountered in the vicinity of the channel. Partings may be in the form of one or more shale layers from several inches to several feet thick. In other cases, the partings occur as intervals of interlaminated coal and shale (Nelson 1983). When a seam is split by partings, one bench of the seam may be left unmined or the parting material may be mined with the coal and separated during cleaning. The action taken depends on several factors, including thickness of the individual benches of coal, thickness and number of partings, and company policy. The experts we interviewed said they would mine a maximum of 1 foot of parting material in the Springfield Coal.

Depth of coal A major cost in opening an underground mine is the cost of constructing slopes or shafts for ventilation and the movement of miners, materials, and coal. The deeper the coal, the more expensive it is to construct these facilities and extract the coal. Although the coals in the Mt. Carmel Quadrangle are as much as 1,200 feet deep, none of the experts interviewed considered mine depth to be a significant factor in limiting the availability of these coals.

Block size and configuration The development of an underground mine entails fixed costs for exploration, land acquisition, mine planning, permitting, and construction of facilities including mine shafts and a preparation plant. The block of coal to be mined must contain enough recoverable tonnage so that the return from selling the coal exceeds the cost of investing in the mine. Forty million tons of recoverable coal are needed to support the operation of an underground mine that includes a preparation plant and rail-loading facilities. If we assume a 50% recovery rate after mining, cleaning, and loading, a mine block of 80 million tons of coal in-place is the minimum needed.

As with surface minable coal, the minimum block size can be achieved by mining multiple seams from a single shaft or drift. The coal resources with insufficient block sizes in the Mt. Carmel Quadrangle do not appear to be situated relative to other minable deposits so that they could be mined as part of a multiseam operation with another seam.

Smaller blocks are feasible for mining under certain conditions. For example, if the seam can be reached by an entry from the highwall of a surface mine, and if existing preparation and rail-loading facilities can be used, initial development costs will be low and a block of only 20 million tons of in-place coal may be sufficient. Given the relatively great depth of the coals in the Mt. Carmel Quadrangle and the sub-

sequent high cost of exploring and developing and operating a mine, blocks smaller than 80 million tons are unlikely to be developed.

Poor mining conditions Unstable mine roof, abrupt variations in seam thickness, washouts of the seam, and other features create poor mining conditions. Such circumstances cause dangerous working conditions for miners, slow the rate of advance, require additional materials and extra procedures for roof control, and increase the costs of transporting coal from the mine face and washing coal. Companies will mine under these conditions for short distances if they think they will eventually encounter better conditions. However, large areas of poor mining conditions will generally be avoided. These conditions are difficult to predict and delineate without data from closely spaced drill holes and a record of extensive experience in mines with identical geology. In our study area, mining conditions are well documented only for the Springfield Coal. The mining conditions that may be encountered in other seams are unknown.

The likelihood of encountering unstable roofs, partings, or washouts in the Springfield Coal increases with proximity to the Galatia Channel. These features are difficult to detect and trace even with closely spaced drill holes. Mines are generally laid out so that areas of potential problems can be probed by mining and abandoned if conditions become unfavorable. Mining has advanced close to the channel in some areas, but severe problems were encountered as much as 1 mile from the channel in other areas. To obtain a rough estimate of the amount of coal that may be restricted from mining due to partings, unstable roofs, or other adverse geologic conditions related to the Galatia Channel, this study considered coal within 0.5 mile of the channel to be unavailable for mining. This coal may ultimately be found to be minable in some areas, while coal farther from the channel will likely be found to be unminable in other areas.

Restricted mining in faulted areas The company experts we interviewed told us that underground mining near faulted areas in the Mt. Carmel Quadrangle was not considered a major problem that would lead to a reduction of resources. However, examination of mining practices along the New Harmony Fault Zone indicated that, in practice, a zone of 100 to 500 feet was often left unmined along the fault zone. In discussions, we learned that this was due to the fact that minor parallel faults were encountered along the eastern upthrown block and intense jointing occurred in the roof strata, which led to mining problems. On the western downthrown block, a substantial dip was often present in the coal due to reverse drag, making it difficult to recover the coal in a narrow strip adjacent to the fault zone. We calculated the resources that would be excluded by a 200-foot buffer along the New Harmony Fault Zone and found that only 2.8 million tons of available deep minable coal (or 0.6% of the total) would be excluded. Because the amount of coal affected is so small, we followed the practice of the companies interviewed and did not exclude any available resources in our final tabulations.

Although faults are not a feature that the experts we interviewed said would affect the availability of coal, they represent an important cost factor. If a second segment of the New Harmony Fault Zone extends into the quadrangle (as we suspect it may), then it is also possible that cross faults like those reported by Bristol and Treworgy (1979) for an area to the immediate south of the quadrangle exist between the two parallel segments. A drilling program may be advisable in this area to at least delineate the cross faults and to confirm the existence and extent of the suspected second fault segment of the New Harmony Fault Zone (Koehl and Meier 1983).

Land use restrictions Except for requiring a 200-foot buffer between underground mines, state laws do not specifically prohibit underground mining of any area. Rules governing the mining of certain features have the effect, however, of prohibiting or severely restricting the mining of these areas. For example, damage caused to surface structures by mine subsidence must be repaired, even if the companies have subsidence rights. Consequently, it is generally not economical to mine under towns. Also, the regulations controlling the disturbance of cemeteries, as discussed previously, must be adhered to by underground mines.

Mining is feasible under most roads, railroads, pipelines, and transmission lines, but mine layouts are generally planned to keep mining under these features to a minimum. Because of the cost of mitigating subsidence damage, the undermining of interstate highways and main railroad lines is avoided, except where necessary for main entries to gain access to coal.

Buffers must be left around oil wells unless they are abandoned and known to be adequately plugged. Large concentrations of wells are a potential obstruction to mining, but they do not appear to be a signifi-

cant restriction on the availability of coal in the Mt. Carmel Quadrangle. Although the density of oil wells is relatively high in the central portion of the Mt. Carmel Quadrangle (fig. 5), many of the oil wells are abandoned or produce only small amounts of oil (stripper wells). The coal companies interviewed indicated that they mine through wells that are abandoned or that can be purchased, re-plugging them if they are not known to be adequately plugged. Pillars are left around wells that cannot be plugged. Because room-and-pillar mines can generally be laid out so that most of the wells are within the normal mine pillars, no coal in the area was considered to have restricted availability due to oil wells.

Environmentally sensitive areas, such as rivers and floodplains, are potential restrictions to underground mining. To receive a permit to mine in these areas, companies must demonstrate that mining will not cause flooding or environmental damage. The Wabash River and its floodplain are potentially sensitive areas in the Mt. Carmel Quadrangle. However, a nearby mine has demonstrated that mining can be successfully carried out without damaging these features; therefore, they are not considered to restrict mining in this area.

Multiple-seam restrictions Where two or more seams of minable thickness are present, both seams generally cannot be mined unless the strata between them (interburden) are sufficiently thick and competent (Chekan et al. 1986). If the interburden is too thin, ground control problems may occur in both the upper and lower seams. The thickness of interburden required depends on several geologic and engineering parameters, including the method and sequence of mining the seams (Hsiung and Peng 1987a, b).

The consensus among the experts we interviewed was that a minimum of 40 feet of interburden, regardless of its lithology, was required to permit mining of two seams in an underground multiseam operation. None of the interburden intervals in the Mt. Carmel Quadrangle were less than this minimum thickness. According to the experts interviewed, the interburden between the main seams, the Herrin, Springfield, and Davis Coals, is sufficient to permit mining of all of them within a given area in any sequence.

Coal quality Data on coal quality are available only for the Keensburg and Friendsville Coals (table 3). However, based on analysis from nearby areas, most of the coals in this quadrangle are expected to have sulfur contents of 2% to 6% and heating values of 11,000 to 12,600 Btu/lb (as-received basis). There is a possibility of some low-to medium-sulfur coals in the Springfield Coal along the Galatia Channel. Adjacent to this paleochannel, where the coal is overlain by thick Dykersburg Shale, sulfur content of the coal ranges from less than 1% to slightly less than 2%. This area in the Mt. Carmel Quadrangle is less than 2 square miles in size, and most of it is within 0.5 mile of the channel. In the rest of the quadrangle, the

Table 3 Range of typical analyses of the Keensburg and Friendsville Coals on an as-received basis.

Type of analysis	Average	Minimum	Maximum
Keensburg Coal (3 samples)*			
Moisture (%)	11.7	11	12.3
Ash (%)	10.3	8.8	11.7
Volatile matter (%)	NA	NA	NA
Fixed carbon (%)	NA	NA	NA
Sulfur (%)	2.7	2.5	3.3
Heating value (Btu/lb)	11,175	11,048	11,302
Friendsville Coal (10 samples)**			
Moisture (%)	10.2	7.1	14.2
Ash (%)	13.7	6.6	19.6
Volatile matter (%)	37.1	31.9	41.1
Fixed carbon (%)	40.7	38.2	42.5
Sulfur (%)	2.4	1.5	3.5
Heating value (Btu/lb)	11,088	10,359	11,233

*Only two of these analyses included a heating value.

**Only four of these samples had volatile matter and fixed carbon analyses, and seven had the heating value calculated.

Springfield Coal probably has a sulfur content typical of other coals in the quadrangle. Although demand for high-sulfur coals has been declining as a result of clean air regulations, these resources cannot be considered unavailable on the basis of their sulfur content because they can be used when blended with low-sulfur coal or as cleaning technology improves.

COAL RESOURCES AND AVAILABLE COAL IN THE MT. CARMEL QUADRANGLE

Coal resources of the Mt. Carmel Quadrangle were calculated using the standard ISGS classification system for surface and deep minable coals (table 4).

The amount of coal available for future development in the Mt. Carmel Quadrangle was calculated on the basis of criteria derived from the interviews with mining experts (table 2). According to these criteria, the ranges of depth for surface and deep minable coals overlap one another and differ from the depth limits used for the standard definition of resources in the ISGS coal resource classification system. The maximum depth for surface mining is 175 feet, but the minimum depth of underground mining is 75 feet if bedrock cover is 75 feet. Because of these definitions, some coal deposits are potentially both surface and deep minable.

Total original resources for the nine seams underlying the quadrangle are 1.1 billion tons. The amount of coal that has been mined is negligible, so remaining resources are also 1.1 billion tons. Nearly 415 million tons (38%) of the resources are estimated to be available for mining (table 4). Nearly 63% of the surface minable resources is available; only 36% of the deep minable resources is available. Available surface minable coal is from the Keensburg and Friendsville Coals, and the available deep minable coal is from the Springfield and Davis Coals. Technological factors (seam thickness, mining block size, stripping ratio, and proximity to the Galatia Channel) account for the majority of the unavailable tonnage (601 million tons, or 54% of original resources; fig. 16). Land use restrictions (proximity to towns, cemeteries, and railroads) account for the remaining unavailable resources (84 million tons, or 8% of original resources).

Of the 86 million tons of original surface minable resources, 63% (54 million tons) is available for mining (table 4, fig. 17). None of the deep minable resources that are potentially surface minable (i.e., 150–175 feet deep) are actually available for surface mining because of high stripping ratios and small block sizes (table 4). Twenty-nine percent of the original surface minable resources is unavailable because the maximum average stripping ratio is greater than 25:1. An additional 6% of the resources occurs in blocks of less than 11 million tons, and 2% is restricted by land use factors (table 4, fig. 17).

Of the more than 1 billion tons of original deep minable resources in the Mt. Carmel Quadrangle, 36% (362 million tons) is available for mining (table 4, fig. 18). None of the more than 8 million tons of surface minable resources that are potentially deep minable are available for underground mining (table 4). The factors restricting the availability of the original deep minable resources are, in order of significance, coal thickness of less than 4 feet (49%), land use restrictions (8%), mining block of less than 80 million tons in-place (6%), and coal within 0.5 mile of the Galatia Channel (1%; table 4, fig. 18).

Common Resource/Reserve Classifications and Available Coal

Federal and state agencies responsible for estimating coal resources and reserves use special terms to describe the relative degree of geologic certainty and economic minability of deposits. Two widely reported categories are “original identified resources” and “demonstrated reserve base” (Wood et al. 1983).

Identified resources This category is generally used to report resources of coal in the USGS resource classification system. It represents resources for which “the location, rank, quality, and quantity are known or estimated from specific geologic evidence” (Wood et al. 1983). In the Mt. Carmel Quadrangle, all of the resources are classed as identified (1.1 billion tons), of which 38% (415 million tons) is available for mining (table 4).

Demonstrated reserve base The Energy Information Administration (EIA) of the U.S Department of Energy (US DOE) maintains estimates of the demonstrated reserve base (DRB) of coal in the United States. The DRB represents coal resources in the ground considered to have a high degree of geologic assurance and a sufficient degree of economic minability. Demonstrated reserve base figures are commonly used for purposes of planning, particularly for forecasting the source, characteristics, and price of future coal supplies.

Table 4 Coal resources for the Mt. Carmel Quadrangle (thousands of tons)

Surface minable coal resources								
Coal name	Original	Available	Land use restrictions			Stripping ratio	Technological restrictions (<11 million tons)	
			Towns	Railroads	Cemeteries		Small blocks	
Keensburg (<150 ft)	19,220	19,031	0	57	133	0	0	0
Friendsville (<150 ft)	41,204	34,913	249	663	103	5,024	249	249
Witt (<150 ft)	25,302	0	78	540	23	19,694	4,967	4,967
Witt (150–175 ft) (also included in deep minable resources)	6,530	0	43	0	42	5,490	955	955
Total (<150 ft) Percentage	85,726 100	53,944 63	327 <1	1,260 1	259 <1	24,718 29	5,216 6	5,216 6
Total (150–175 ft) Percentage	6,530 100	0 0	43 1	0 0	42 1	5,490 84	0 15	0 15

Deep minable coal resources								
Coal name	Original	Available	Land use restrictions			<4ft thick	Technological restrictions	
			Towns	Railroads	Cemeteries		Block size	Channel
Danville	149,199	0	13,832	239	153	130,900	4,075	0
Herrin	229,420	0	18,580	1,064	529	155,436	53,812	0
Springfield	302,988	189,158	16,583	3,579	700	75,696	3,499	13,773
Houchin Creek	44,230	0	620	0	54	42,521	1,036	0
Dekoven	19,817	0	31	0	25	19,761	0	0
Davis	266,569	172,642	21,994	3,250	502	68,181	0	0
Witt (>150 ft)	2,334	0	0	0	0	2,334	0	0
Witt (75–150 ft) (also included in surface resources)	8,324	0	0	0	0	8,324	0	0
Total (>150 ft) Percentage	1,014,557 100	361,800 36	71,640 7	8,132 1	1,963 <1	494,829 49	62,422 6	13,773 1
Total (75–150 ft) Percentage	8,324 100	0 0	0 0	0 0	0 0	8,324 100	0 0	0 0
Total (all resources) Percentage	1,100,283 100	415,744 38	71,967 7	9,392 1	2,222 <1	494,829 45	67,638 6	13,773 1

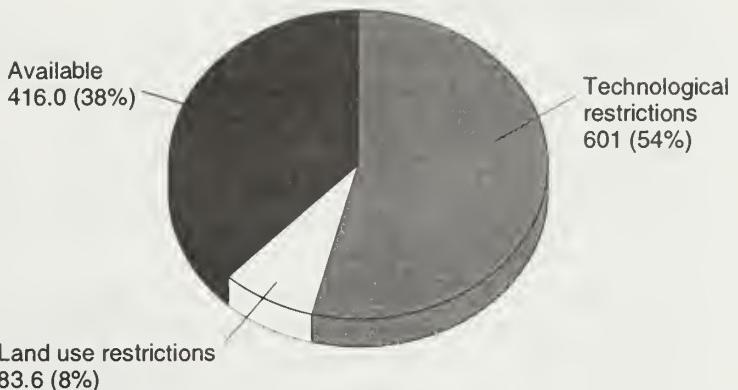


Figure 16 Availability of coal resources in the Mt. Carmel Quadrangle (millions of tons and percentage of original resources).

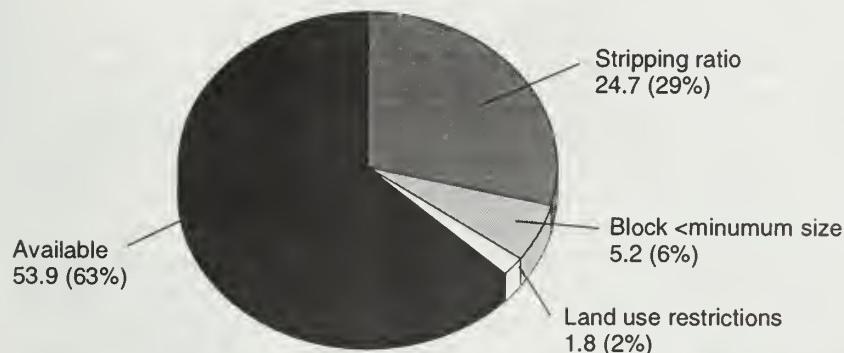


Figure 17 Factors restricting the availability of surface minable coal in the Mt. Carmel Quadrangle (millions of tons and percentage of original resources that are surface minable).

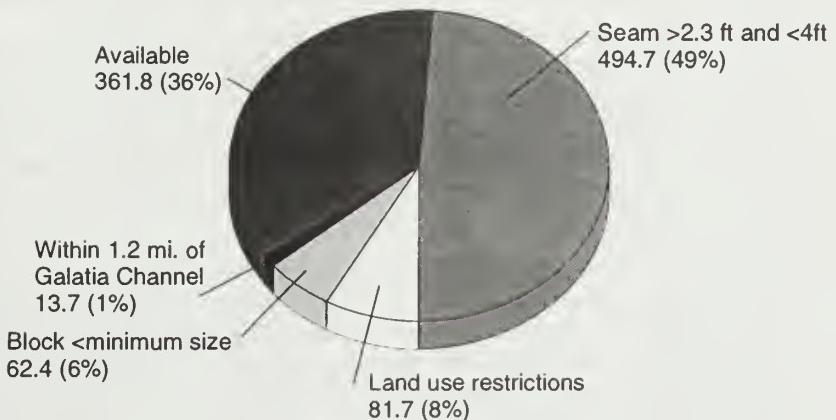


Figure 18 Factors restricting the availability of deep minable coal in the Mt. Carmel Quadrangle (millions of tons and percentage of original resources that are deep minable).

For Illinois, the DRB consists of resources in the "proved" and "probable" categories of geologic assurance. The coal may be 18 or more inches thick and less than 150 feet deep or 28 or more inches thick and less than 1,000 feet deep. About 26%, or 283 million tons, of the resources in the Mt. Carmel Quadrangle is classified as part of the demonstrated reserve base. It is interesting to note that the estimated available resources exceed the DRB by more than 132 million tons (47%) because most of the data used to estimate the resources are from oil test geophysical logs and such data, by definition, do not have a sufficiently high degree of geologic assurance to qualify for use in the DRB.

Available Resources by Seam

Of the nine seams with resources in the Mt. Carmel Quadrangle, only four are found to have resources available for mining as defined here. Most of the exclusions (88%) are the result of technological factors, including seam thickness, block size, and stripping ratios.

Keensburg Coal Total resources of Keensburg Coal in the Mt. Carmel Quadrangle are 19.2 million tons (table 4), all less than 150 feet deep and classified as surface minable. Just greater than 19 million tons (99%) of these resources are available for mining. Approximately 190,000 tons are excluded because of land use restrictions (table 4, fig. 19).

Friendsville Coal The 41.2 million tons of Friendsville Coal resources in the Mt. Carmel Quadrangle are all surface minable because they are less than 150 feet deep (table 4). Nearly 35 million tons (85%) of the original identified Friendsville resources are classified as available for mining. Roughly 1 million tons (about 2.5%) are excluded because of land use restrictions and about 5 million (13%) because of technological restrictions, primarily an average stripping ratio that exceeds 20 to 1 (table 4, fig. 20).

Witt Coal For the Witt Coal, there are resources of almost 28 million tons (table 4). Slightly more than 25 million tons are less than 150 feet deep and are classified as surface minable. Another 6.5 million tons of Witt Coal, which are 150 to 175 feet deep and greater than 18 inches thick, traditionally at depths we normally assign to only deep minable coals, are herein also classified as surface minable because of mining practices (table 4). Only 2.3 million tons of the Witt Coal are deeper than 150 feet and greater than 4 feet thick and thus classified in the traditional deep minable coal category (table 4). However, an additional 8 million tons of the surface minable coal are also classified as deep minable using the 75 foot minimum depth and bedrock factor; these resources are thus classified in both categories in table 4.

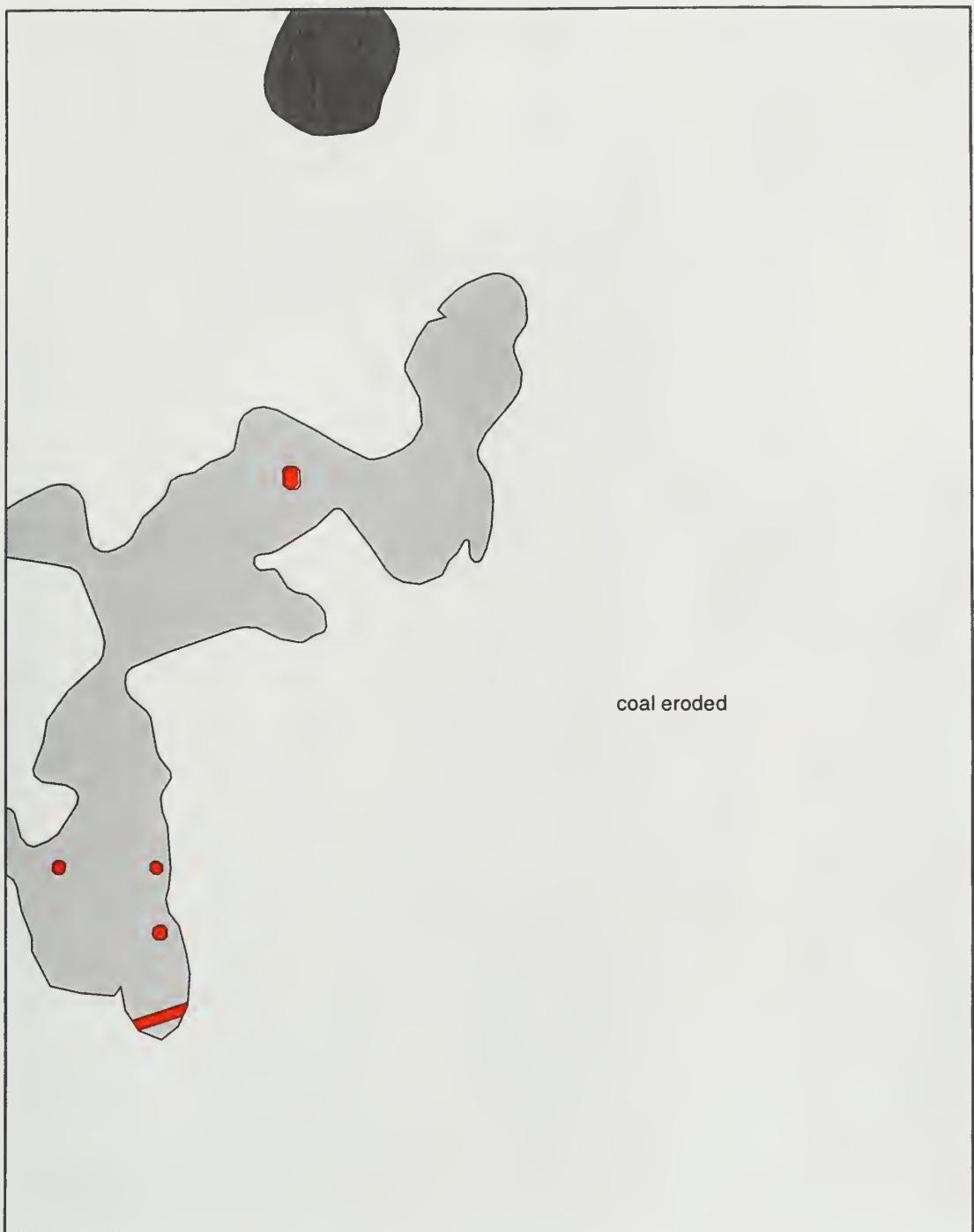
None of the coal resources in the Witt are classified as available for either surface or deep mining (table 4). Nearly 26 million tons (81%) of the surface minable resources are thin and unavailable because the average stripping ratio exceeds 25 to 1. The remainder is unavailable because the blocks are too small (6 million tons, or 19%) or because of land use restrictions (0.2 million tons, or less than 1%). The deep minable resources are unavailable because they are less than the required 4 feet thick.

Danville Coal Nearly 150 million tons of deep minable resources are estimated for the Danville Coal in this quadrangle (table 4). None of these resources are classified as being available for mining. Most of the exclusions (nearly 131 million tons, or 88%) are caused by coal less than the minimum thickness of 4 feet. Land use exclusions of about 14 million tons (9%) are the second significant factor in making the Danville unavailable for mining, primarily because of the unavailability of the coal beneath the town of Mt. Carmel. Other technological restrictions (e.g., block size less than 80 million tons) make up the remaining exclusions of more than 4 million tons (nearly 3%).

Herrin Coal More than 229 million tons of deep minable resources are identified for the Herrin Coal in the Mt. Carmel Quadrangle (table 4). None of these resources are classified as being available for mining. Like the overlying Danville Coal, the primary exclusion (155 million tons, or 68%) is caused by coal less than the minimum thickness of 4 feet. Technological restrictions exclude almost 54 million tons (24%) of coal because of mining blocks smaller than the required 80 million tons. The remaining exclusions of about 20 million tons (8%) are due to land use restrictions, primarily because the coal lies beneath the town of Mt. Carmel.

Springfield Coal Almost 303 million tons of deep minable resources are estimated for the Springfield Coal, 189 million tons of which are classified as available for mining (table 4). The primary exclusions are technological (93 million tons, or 30%) and result from coal less than 4 feet thick (75.7 million tons, or 25%), coal within 0.5 mile of the Galatia Channel (almost 13.8 million tons, or 5%), and block sizes of less than 80 million tons (3.5 million tons, or 1%) (table 4, fig. 21). Another 20.9 million tons (7%) are excluded because of land use restrictions, primarily coal within 200 feet of towns.

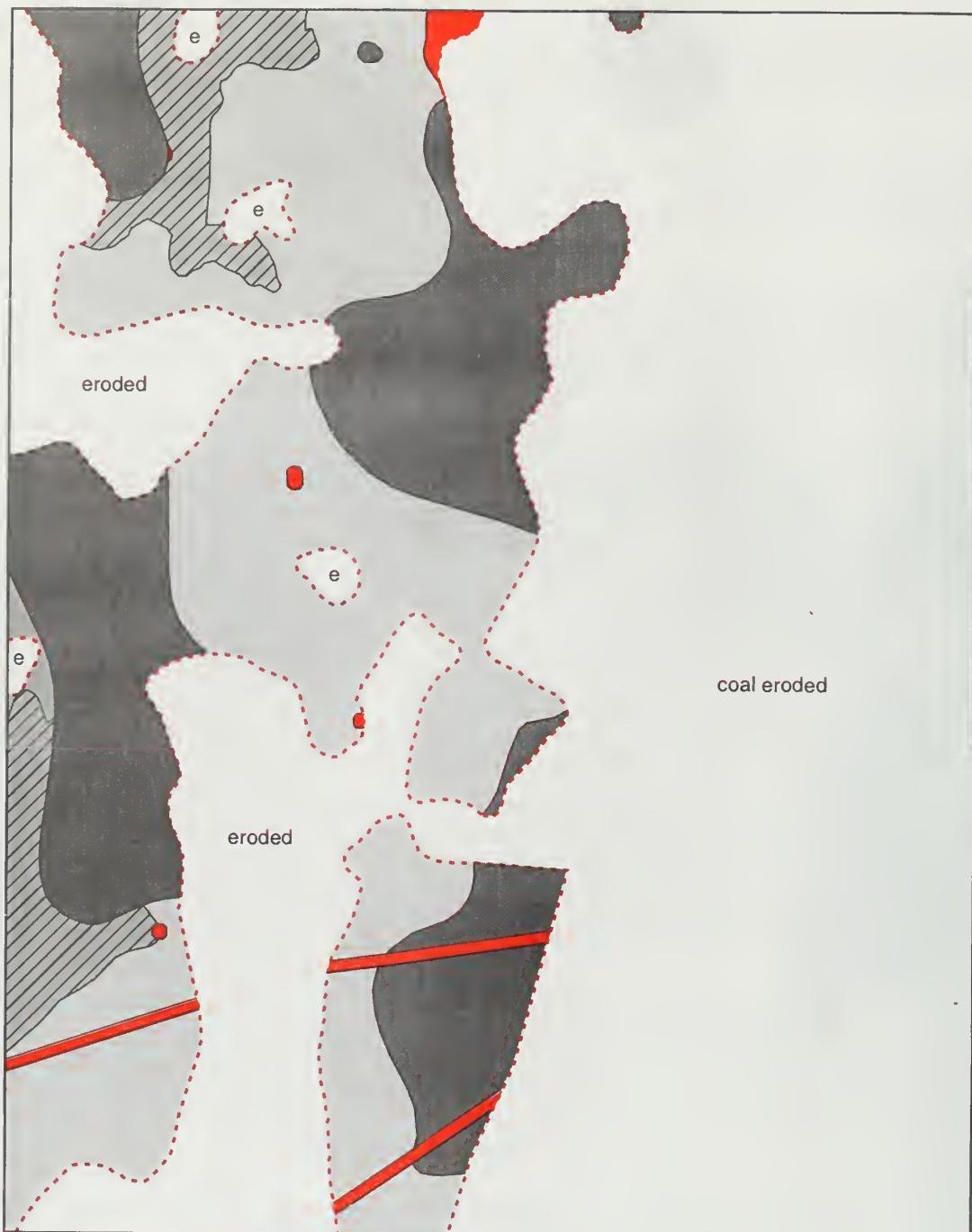
Houchin Creek Coal A little more than 44 million tons of deep minable resources are estimated for the Houchin Creek Coal within the quadrangle (table 4). None of these resources are classified as being available for mining. Most of the coal (42.5 million tons, or 96%) is less than the minimum required thickness of 4 feet. Another 1 million tons (2%) are thick enough, but they occur in a mine block far smaller than the



resources available for mining
 coal <1.5 ft thick
 restricted by land use

N
0 1 mi

Figure 19 Availability of resources for surface mining, Keensburg Coal, Mt. Carmel Quadrangle.



- resources available for mining
- block <11 million tons in-place
- restricted by land use
- unfavorable stripping ratio
- coal <1.5 ft thick

- subcrop of Friendship Coal
- e coal eroded



Figure 20 Availability of resources for surface mining, Friendsville Coal, Mt. Carmel Quadrangle.

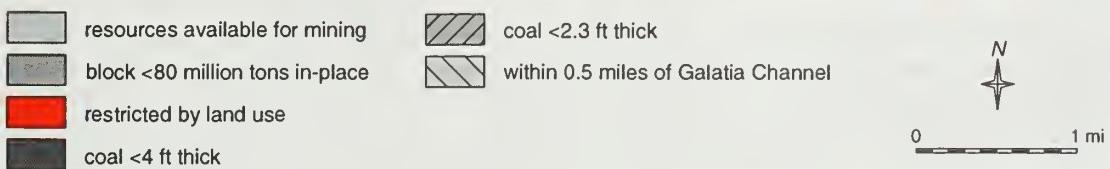


Figure 21 Availability of resources for underground mining, Springfield Coal, Mt. Carmel Quadrangle.



- [Light Gray Box] resources available for mining
- [Red Box] restricted by land use
- [Dark Gray Box] coal <4 ft thick
- [Hatched Box] coal <2.3 ft thick



Figure 22 Availability of resources for underground mining, Davis Coal, Mt. Carmel Quadrangle.

80 million tons of coal in-place required. The remaining approximately 0.6 million tons (1%) are excluded because of land use restrictions.

Dekoven Coal The Dekoven Coal, which lies just above the Davis Coal, has nearly 20 million tons of estimated deep minable resources in the quadrangle. However, 99% of these resources is not available because the coal is below the minimum thickness of 4 feet; the remaining 1% is unavailable due to land use restrictions (table 4).

Davis Coal The Davis Coal, having almost 267 million tons, is second to the Springfield Coal in deep minable resources (table 4). About 173 million tons (65%) of the resources in the Davis are classified as available for deep mining. Technological exclusions total slightly more than 68 million tons (26%) for coal less than 4 feet thick (table 4, fig. 22). The remaining 25.8 million tons (10%) are unavailable due to land use restrictions within 200 feet of towns.

CONCLUSIONS

Of the 1.1 billion tons of coal resources in the Mt. Carmel Quadrangle, only 416 million tons (38%) are available for mining. Nearly 86 million tons of the resources are classified as surface minable, of which 54 million tons (63%) are considered to be available for mining. Factors that restrict the availability of coal for surface mining include unfavorable stripping ratios (29%); small mining blocks (6%); and proximity to towns, railroads, and cemeteries (2%). Almost 362 million tons of the available coal are classified as deep minable. Factors restricting the availability of the remaining 653 million tons of deep minable resources include thin seam thickness (49%); proximity to towns, cemeteries and railroads (8%); small mining blocks (6%); and proximity to the Galatia Channel (1%). These factors are likely to affect the availability of coal in other parts of the deep portion of region 4 in the Illinois Basin.

This study found that closely spaced oil wells and the Wabash Valley Fault System do not seriously restrict the availability of coal resources. Past ISGS resource studies identified more than 9 billion tons of coal statewide classified as restricted because of oil wells. The findings from this assessment suggest that much of this coal may be available for mining. Additional quadrangles will be examined to test these findings.

Although ISGS studies have never excluded coal resources in the vicinity of the Wabash Valley Fault System, it was thought that mining might be restricted by this feature. The experience of mining in this area to-date has been that only a small percentage of the resources becomes inaccessible or unminable because of the fault system.

The available resources in the Mt. Carmel Quadrangle are considerably higher than the Demonstrated Reserve Base (DRB) (416 versus 283 million tons). This is true primarily because much of the data used to map the resources for this study consisted of wireline logs from oil test holes, a source of data not considered reliable enough to qualify for inclusion in the DRB. We have found wireline logs to be a useful tool in determining coal thickness to an accuracy of ± 1 foot.

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APPENDIX BACKGROUND AND FRAMEWORK OF STUDIES OF AVAILABLE COAL IN ILLINOIS

Previous Investigations of Available Coal Resources

The difference between estimates of Illinois' total coal resources and the portion of the resources available for development was discussed as early as 1969 by Risser and later by Attanasi and Green (1981). Zwartendyk (1981) described this difference as a major problem with all estimates of mineral resources.

Recognizing the need for estimates of available coal, Treworgy et al. (1978) used a relatively simple set of criteria to make a general, statewide assessment of surface minable resources in Illinois. Treworgy and Bargh (1982) conducted a similar examination of deep minable resources in the state. The latter study ranked coal into four categories of development potential: high, moderate, low, and restricted. Deposits with a high potential for development had characteristics similar to deposits currently being mined, whereas those with moderate or low potential had less favorable characteristics. Restricted deposits were considered unminable because of constraints resulting from surface land use or oil fields.

These two studies demonstrated that a large part of the state's coal resources have characteristics that restrict their development potential. Because of the statewide approach used in these studies, however, many factors that restrict the development of coal were not considered; for example, the geology of roof and floor strata, thickness of the interval between seams, and thickness of the bedrock overburden. The actual amount of available coal may thus be significantly lower than indicated by the initial estimates. Treworgy et al. (1978) estimated that 6 billion of the 20 billion tons of surface minable resources are suitable for mining. Industry sources have suggested that the amount of surface minable coal available is actually much lower. The steady decline since about 1970 in the number of surface mines in the state (down from 35 to 15 mines) and the annual percentage of the state's total production from surface mines (down from 51% to 26%) appears to confirm this view.

In 1987, the National Coal Council concluded that lack of information on the availability of coal resources is a nationwide problem that should be rectified. In the late 1980s, the USGS began sponsoring assessments of the availability of coal resources in eastern Kentucky (Eggleston et al. 1988, Carter and Gardner 1989). Studies have since been expanded to include many of the major coal-producing states in the central Appalachians and the Illinois Basin (Jake 1989, Carter et al. 1990, Sites et al. 1991, Weisenfluh et al. 1992, Treworgy et al. 1994, Cetin et al. 1994).

The USGS-sponsored studies examine in detail the factors affecting the availability of coal for mining within a 7.5-minute quadrangle (about 56 square miles). The relatively small study areas permit more complete and comprehensive data collection and assessment than is practical or economical to conduct for a larger area (Eggleston et al. 1990). The quadrangles selected represent the geology and mining conditions found in surrounding quadrangles, and the results of these detailed investigations can be used to estimate the availability of coal resources in these regions.

Framework for Studies of Available Coal in Illinois

The Illinois coal field was divided into seven regions to provide a statewide framework for selecting representative quadrangles and extrapolating results from individual quadrangle studies to larger areas. Each region had a distinct combination of coal resources and geologic and physiographic characteristics (fig. 1). The La Salle Anticlinorium roughly follows the boundary between regions 4 and 5, and the Du Quoin Monocline separates region 6 from 4 and 7. The other boundaries are arbitrary, but they serve to divide the central part of the basin (region 4) from the surrounding shelf areas.

The resources of most individual coal seams are concentrated in one or two regions. For example, the resources of Danville Coal are primarily in regions 1 and 5; the Jamestown and Survant Coals are primarily in region 5; the Seelyville, Davis, and Dekoven Coals are in regions 4, 5, and 7; and the resources of the Colchester Coal are primarily in regions 1 and 2. The Springfield and Herrin Coals have resources in all regions.

Significant quantities of coal resources remain in all regions (fig. A-1), and all but regions 1 and 2 have significant resources with a low to medium sulfur content (fig. A-2). All regions have had a large amount of production (fig. A-3), and all but region 1 are currently producing some coal (fig. A-4). The disproportionate

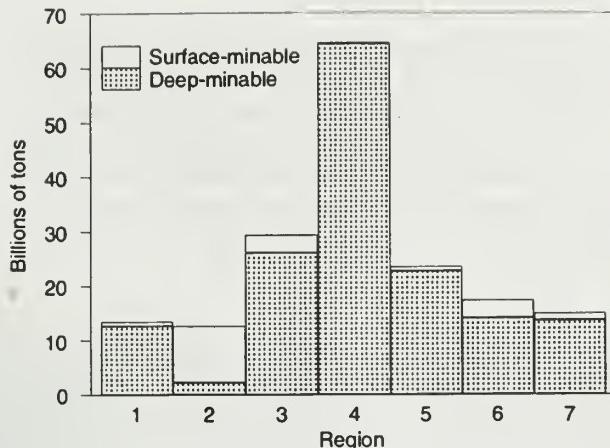


Figure A-1 Remaining coal resources in each region.

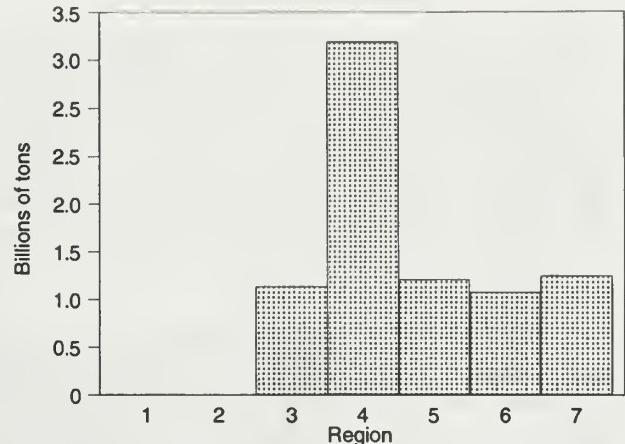


Figure A-2 Remaining resources of low- to medium-sulfur coal in each region.

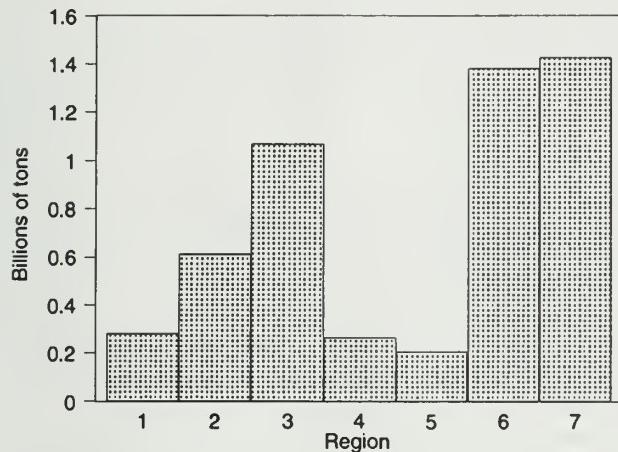


Figure A-3 Historical record of coal production in each region.

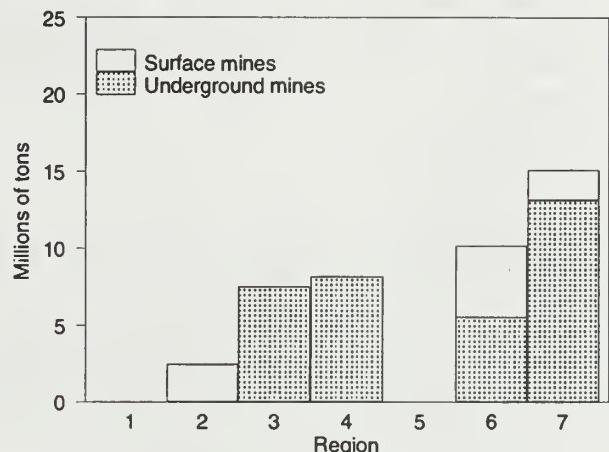


Figure A-4 Total coal production in each region for 1993.

Table A-1 Guidelines for selection of quadrangle study areas.

- The minimum sample size for a region is two quadrangles. Three or four quadrangles may be needed to sample all of the significant combinations of seams, mining conditions, and physiography.
- Select at least one quadrangle per region with surface minable resources and one with deep minable resources.
- Quadrangles should generally contain a significant quantity of resources screened as having a high potential for development*.
- All seams in the region that have resources with a high potential for development should be represented by at least one quadrangle.
- Selected quadrangles should include all the significant land cover/land use settings characteristic of the region.
- Select at least one quadrangle in each of the major low-sulfur deposits (Quality Circle, Hornsby, Troy, Charleston, Galatia, Darwin, Murphysboro, and Francis Creek).

* The term "high development potential" is defined for deep minable coal in Treworgy and Bargh (1982) and has been extended to include the reserve blocks of surface minable coal delineated in Treworgy et al. (1978).

amount of mining in certain regions relative to the quantity of resources in each region is an indication that large amounts of resources may be unavailable for mining.

Two to four quadrangles must be assessed in each region to obtain a sample suitable for characterizing the availability of the resources of that region (see table A-1). A total of 26 quadrangles have been identified for study (see fig. 1). The proposed quadrangles will be re-evaluated periodically as the study progresses. Some quadrangles may be dropped and others added to address new factors that may be identified or to incorporate new data that may become available.

Quality of Coal Resources

Although the quality of coal is an important factor in determining the market demand for specific deposits and consequently their value, coal quality is not assessed in this study. The techniques used to combine coal quality characteristics with resource data differ substantially from the quadrangle mapping approach used to assess available coal. Several of the important coal quality characteristics can easily be mapped statewide using regional trends or geologic associations (e.g., sulfur, rank, and chlorine). The distribution of other parameters is not well understood and additional sampling is needed (e.g., ash and certain trace elements). The quality of a delivered coal product is also dependent on the coal's washability and the handling and preparation procedures used by individual mines. The ISGS is currently studying the quality of delivered coals (Demir et al. 1994). For these reasons, the quality of coal resources will be assessed in a separate study.

REFERENCES

- Attanasi, E.D., and E.K. Green, 1981, Economics and coal resource appraisal—Strippable coal in the Illinois Basin: *Southern Economic Journal*, v. 47, no. 3, p. 742–752.
- Bristol, H.M., and J.D. Treworgy, 1979, The Wabash Valley Fault System in Southeastern Illinois: Illinois State Geological Survey, Circular 509, 19 p.
- Cady, G.H., 1952, Minable Coal Reserves of Illinois: Illinois State Geological Survey, Bulletin 78, 138 p.
- Carter, M.D., and N.K. Gardner, 1989, An Assessment of Coal Resources Available for Development: U.S. Geological Survey, Open-File Report 89-362, 52 p.
- Carter, M.D., N.K. Gardner, R.E. Sergeant, E.V.M. Campbell, and N. Fedorko III, 1990, Coal availability studies—A progress report, in USGS Research on Energy Resources, 1990: U.S. Geological Survey, Circular 1060, p. 13–14.
- Cetin, H., C. Conolly, and J.A. Rupp, 1994, The Coal Availability Study in Indiana—Alfordsville 7.5-minute Quadrangle: Indiana Geological Survey, Open-File Report 94-8, 53 p.
- Chekan, G.J., R.J. Matetic, and J.A. Galek, 1986, Strata Interactions in Multiple-Seam Mining—Two Case Studies in Pennsylvania: United States Bureau of Mines, Report of Investigations 9056, 17 p.
- Demir, I., R. Harvey, R. Ruch, H. Damberger, C. Chaven, J. Steele, and W. Frankie, 1994, Characterization of Available (Marketed) Coals from Illinois Mines: Illinois State Geological Survey, Open File Series 1994-2, 26 p.
- Eggleston, J.R., M.D. Carter, and J.C. Cobb, 1988, Available coal resources—A pilot study, in USGS Research on Energy Resources, 1988: U.S. Geological Survey, Circular 1025, p. 15.
- Eggleston, J.R., M.D. Carter, and J.C. Cobb, 1990, Coal Resources Available for Development—A Methodology and Pilot Study: U.S. Geological Survey, Circular 1055, 15 p.
- Hsiung, S.M., and S.S. Peng, 1987a, Design guidelines for multiple seam mining, part I: Coal Mining, v. 24, p. 42–46.
- Hsiung, S.M., and S.S. Peng, 1987b, Design guidelines for multiple seam mining, part II: Coal Mining, v. 24, p. 48–50.
- Jake, T., 1989, Available coal resources in West Virginia, in *Mountain State Geology*: West Virginia Geological and Economic Survey, p. 7–10.
- Koehl, K.W., and D. Meier, 1983, Mining across the New Harmony Fault, Wabash County, Illinois: Proceedings of the Illinois Mining Institute, p. 35–43.
- Nance, R.B., and C.G. Treworgy, 1981, Strippable Coal Resources of Illinois, Part 8—Central and Southeastern Counties: Illinois State Geological Survey, Circular 515, 32 p.

- National Coal Council, 1987, Reserve Data Base Report of the National Coal Council, 24 p.
- Nelson, W.J., 1991, Chapter 16: Structural styles of the Illinois Basin, in M.W. Leighton, D.R. Kolata, D.F. Oltz, and J.J. Eidel, editors, Interior Cratonic Basins: American Association of Petroleum Geologists Memoir 51, p. 209–243.
- Risser, H.E., 1969, Coal strip mining—Is it reaching a peak?: Transactions of the Society of Mining Engineers, v. 244, p. 245–249.
- Sites, R.S., E.V.M. Campbell, and K.K. Hostettler, 1991, Restrictions to mining—Their effect on available coal resources, in D.C. Peters, ed., Geology in Coal Resource Utilization: TechBooks, Fairfax, VA, p. 81–94.
- Smith, W.H., 1957, Strippable Coal Reserves of Illinois, Part 1—Gallatin, Hardin, Johnson, Pope, Saline, and Williamson Counties: Illinois State Geological Survey, Circular 228, 39 p.
- Treworgy, C.G., and M.H. Bargh, 1982, Deep-Minable Coal Resources of Illinois: Illinois State Geological Survey, Circular 527, 65 p.
- Treworgy, C.G., L.E. Bengal, and A.G. Dingwell, 1978, Reserves and Resources of Surface-Minable Coal in Illinois: Illinois State Geological Survey, Circular 504, 44 p.
- Treworgy, C.G., C. Chenoweth, and M.H. Bargh, 1995, Availability of Coal Resources in Illinois, Galatia Quadrangle, Southern Illinois: Illinois State Geological Survey, Illinois Minerals 113, 38 p.
- Treworgy, C.G., G.K. Coats, and M.H. Bargh, 1994, Availability of Coal Resources for Mining in Illinois, Middletown Quadrangle, Central Illinois: Illinois State Geological Survey, Circular 554, 48 p.
- Weisenfluh, G.A., R.E. Andrews, J.K. Hiett, S.F. Greb, R.E. Sergeant, and D.R. Chesnut, Jr., 1992, Available coal resources of the Booneville 7.5-minute Quadrangle, Owsley County, Kentucky: Kentucky Geological Survey, Information Circular 42, 26 p.
- Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975, Handbook of Illinois Stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.
- Wood, G.H., T.M. Kehn, M.D. Carter, and W.C. Culbertson, 1983, Coal Resource Classification System of the U.S. Geological Survey: U.S. Geological Survey, Circular 891, 65 p.
- Zwartendyk, J., 1981, Economic issues in mineral resource adequacy and in the long-term supply of minerals: Economic Geology, v. 76, no. 5, p. 999–1005.

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